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ESTIMATING OPERATING AND SUPPORT COST MODELS FOR U.S. NAVAL SHIPS

by
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 1993

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suit 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (leave blank)

2. REPORT DATE
December/1993

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE
ESTIMATING OPERATING AND SUPPORT COST MODELS FOR U.S. NAVAL SHIPS

5. FUNDING NUMBERS

6. AUTHOR(S)
Ting, Chung-wu

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense of the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12B. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

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This study analyzes the U.S. Navy main combatant vessels' Operating and support (O&S) costs. It seeks to reveal basic relationships of O&S costs through accounting and structural methods. The accounting oriented analysis found the VAMOSC-SHIPS and Jane's combined database to be relatively accurate with the exception of nuclear submarines and nuclear aircraft carriers. The structural analysis found that the overhaul cost should be analyzed separately due to essential differences used to calculate overhaul costs and a 1985 policy revision to ship overhaul. O&S cost relationships between factors other than overhauls were strong. Manpower was found to have the most dramatic effect on determining O&S costs.

14. SUBJECT TERMS

Operating and support cost

15. NUMBER OF PAGES
85

16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298(Rev 2-89)
Prescribed by ANSI Std. 239-18
298-102

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This study analyzes the U.S. Navy main combatant vessels' Operating and support (O&S) costs. It seeks to reveal basic relationships of O&S costs through accounting and structural methods. The accounting oriented analysis found the VAMOSC-SHIPS and Jane's combined database to be relatively accurate with the exception of nuclear submarines and nuclear aircraft carriers. The structural analysis found that the overhaul cost should be analyzed separately due to essential differences used to calculate overhaul costs and a 1985 policy revision to ship overhaul. O&S cost relationships between factors other than overhauls were strong. Manpower was found to have the most dramatic effect on determining O&S costs.

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ACKNOWLEDGMENTS

I wish to express my thanks to my principal advisor, Dr. Katsuaki Terasawa, my associate advisors Dr. Gregory G. Hildebrandt and Dr. Dan C. Boger for their help and guidance. I will also not forget the support and understanding my wife Dinah and two lovely daughters gave me during my hard study.

I. INTRODUCTION

As the Cold War ends, the whole world faces a new military challenge: downsizing the armed forces[1]. Tensions between the free world and communist countries are eased. Because of the nature of democracies, politicians are asked to execute the will of the people, and downsizing the military is a current goal of the post-cold war constituency. But in line with President Bush's recommendations to make the American military "... smaller, but better," the military must ensure that it maintains or improves the quality of its military forces as it reduces its size.

One measure of an improved military is better combat readiness[2], in other words - better trained personnel and better maintained weapons. Operating and support (O&S) costs are costs spent in daily operation and support of the force and hence can be one measurement of combat readiness. Only by understanding the relationships between O&S costs and the factors that affect it can we do any further research to make constructive models or suggestions about modifying O&S costs.

---

[1] Few exceptions are Iraq, Red China, Haiti, etc.

[2] "*Department of Defense Dictionary of Military and Associated Terms*", JCS Pub. 1, 1 April 1984. Readiness is defined as "the ability of forces, units, weapons systems, or equipment to deliver the outputs for which they were designed."

A. LITERATURE REVIEW

An initial study using the same database that this study used was conducted by Katsuaki Terasawa, William Gates and Ku Shin in March of 1993[Ref. 1]. The study categorized the data into eleven groups and used linear and double log regression models to find relationships in O&S costs. Two main statistical weaknesses in this study, serial correlation and heteroskedasticity, were a result of the database being comprised of pooled data.

Another study conducted by the Institute for Defense Analyses (IDA), and titled ***Estimating Operating and Support Costs of Military Forces***, (by Paul F. Goree, 1989 project leader)[Ref. 2] studied a much wider O&S cost area. It performed statistical multivariate regressions on total O&S costs and direct O&S costs and included aircraft carriers, amphibious ships, attack submarines, cruisers, destroyers, frigates, patrol combatants and strategic submarines. The report considered serial correlation and identified ship overhaul costing procedures as causing otherwise unexplainable statistical variations.

Research from the RAND Corporation entitled, ***An Estimation of USAF Aircraft Operating and Support Cost Relations***, by Gregory G. Hildebrandt done in May of 1990[Ref. 3], studied in more detail the Air Force's overall O&S cost structure. Hildebrant's study used averaged annual data and provided a well developed statistical model. His model is used as a structural basis for the aggregate part of this study with modifications for use with Navy ships vice Air Force aircraft.

B. DATABASE DESCRIPTION

The database used in this study is the same combined database used by Terasawa et al and is constructed from three major sources of data: *Visibility and Management of Operating and Supporting Cost - Ships (VAMOSC - SHIPS)*, March 1991; *NAVSEA Historical Cost of Ships*, Naval Sea Systems Command, Cost Estimating and Analysis Division (SEA 017); and *Jane's Fighting Ships*, 1988-1989.

The VAMOSC-SHIPS data is the largest component of the combined database. It contains (1) direct unit costs, (2) direct intermediate maintenance costs, (3) direct depot maintenance costs and, (4) indirect operating costs. There are many clearly defined sub-elements under these four categories. Appendix A provides detailed compositions of these four categories. Because the data provides a level of detail down to individual ships, it can be used to estimate different cost characteristics among different types of ships.

The NAVSEA component of the database provides acquisition cost data for 652 ships in current and constant 1992 dollars and inflation indices. The Jane's component of the database provides annual displacement (tons), commissioning dates, and generating capacity/horsepower data from 1981 to 1990. These D-BASE and STATA (a statistical software package) formatted databases were converted to Statistical Analysis Software (SAS) format on the Naval Postgraduate School's mainframe computer system.

C. OBJECTIVES

The objectives of this study are to:

- Understand and authenticate through operating and support analyses the VAMOSC-SHIPS and Jane's combined database to certify the validity of the database for further analysis.
- Identify basic relationships between O&S costs and factors that affect it and also determine the magnitude of their separate influences on O&S costs.
- Provide a useful database for modeling the effects of changes in operational tempo upon O&S costs.

D. SCOPE OF RESEARCH

This research will focus on the main combatant vessels of the U.S. Navy: Guided Missile Cruisers (CGs), Nuclear Guided Missile Cruisers (CGNs), Aircraft Carriers (CVs), Nuclear Aircraft Carriers (CVNs), Destroyers (DDs), Guided Missile Destroyers (DDGs), Frigates (FFs), Guided Missile Frigates (FFGs), Nuclear Ballistic Missile Submarines (SSBNs) and Nuclear Submarines (SSNs). Other ship types were excluded from this study due to the extremely low numbers of certain ship types[3] or the planned decommissioning of other types[4].

---

[3] Types like AG, AGDS, AGF, AGSS, AR, ARL, ATF, AVM, AVT, BB, LCC, MCM, MSO, PG have five or less ships or less than fifty observations.

[4] Usually the ship types in footnote 3 represent only old ships which were commissioned more than twenty years ago. Type AR ships were all commissioned fifty years ago. Type SS

Two second level sub-elements of the VAMOSC-SHIPS database were not relevant to this study and were excluded. The first was unscheduled repair costs[5] (3.1). Unscheduled repairs are the result of combat casualties, maritime affairs or other unforeseeable occurrences that are beyond the repair capability of the ships. The other was fleet modernization costs[6] (3.2). Fleet modernization costs are costs of performing ship alterations (nuclear alterations and ordnance alterations dependent on the development of new weapon technology) and installing improvements (including military and technical improvements). These activities are not part of normal daily operating and support costs and they were excluded from this analysis.

E. TWO APPROACHES TO ACHIEVE THE OBJECTIVES

In order to attain the stated objectives, this research is divided into two parts. The first part deals with

---

(Submarine) has eight ships, but the newest ship was commissioned in 1959.

[5] Definition for unscheduled repairs in the VAMOSC-SHIPS data is "Cost of depot level maintenance performed at public or private facilities as a result of casualty, voyage damage, and other unforeseeable occurrences which are beyond the repair capability of the ships force."

[6] Definition for fleet modernization in the VAMOSC-SHIPS data is "Cost of installing ship alterations and improvements including military and technical improvements, nuclear alterations and ordnance alterations; cost of other support provided at depot facilities; and costs for centrally - provided material used at public and private facilities. Cost expended for the purchase of spares and other material required due to changes to the ship's Coordinated Shipboard Allowance List (COSAL)."

accounting-oriented regressions. Accounting-oriented regression means using as nearly as possible the constructive relationships among the data to determine the quality of the data. If the regressions closely model the original relationships, then the data is "clean"; that is to say, it is fairly accurate and verifiable. If the regressions do not substantiate the original relationships, then we know that the data is not clean, that the derived data is uncorrelated with the source data from which it was derived, and its inaccuracy may make it unsuitable for use in further analysis.

The second part of the study is to find relationships between O&S costs and factors that theoretically affect these costs using structural equations. These relationships then can be the basis for further simulation and forecasting.

II. DATA AUTHENTICATION

A. PRELIMINARY EFFORTS TO VERIFY THE DATABASE

Initial authentication efforts were by trial and error. Various multivariate regressions were performed using cross-sectional, timewise and individual ship approaches, none of which yielded useful results. Appendix B is a partial list of preliminary multivariate regressions conducted that are representative of the direction and efforts made to verify the accuracy of the database. Finally, a model for dealing with pooled data was provided by Professor Dan Boger and is the basis for the statistical regression models used in verifying the accuracy of the pooled data.

B. DATA AUTHENTICATION PROCEDURE

Authenticating the data is a somewhat complex task. The Navy has over six hundred ships with varying operational tempos, sizes and other unique characteristics. The VAMOSC-SHIPS database provides details of these and other characteristics such as manpower and maintenance requirements. Outlying values in the database could skew statistical regression results, and pooled datasets present problems of statistical serial correlation and heteroskedasticity. To deal with these problems requires the development of a data authentication procedure in order to proceed with the analyses. The flow chart in Figure 1 illustrates the procedure that was developed to authenticate this dataset.

The procedure can be divided into four parts: (1) grouping data, (2) specification of each group, (3) robust regression, and (4) treating serial correlation and heteroskedasticity weaknesses in pooled datasets. The following sections will describe each part of the procedure in detail.

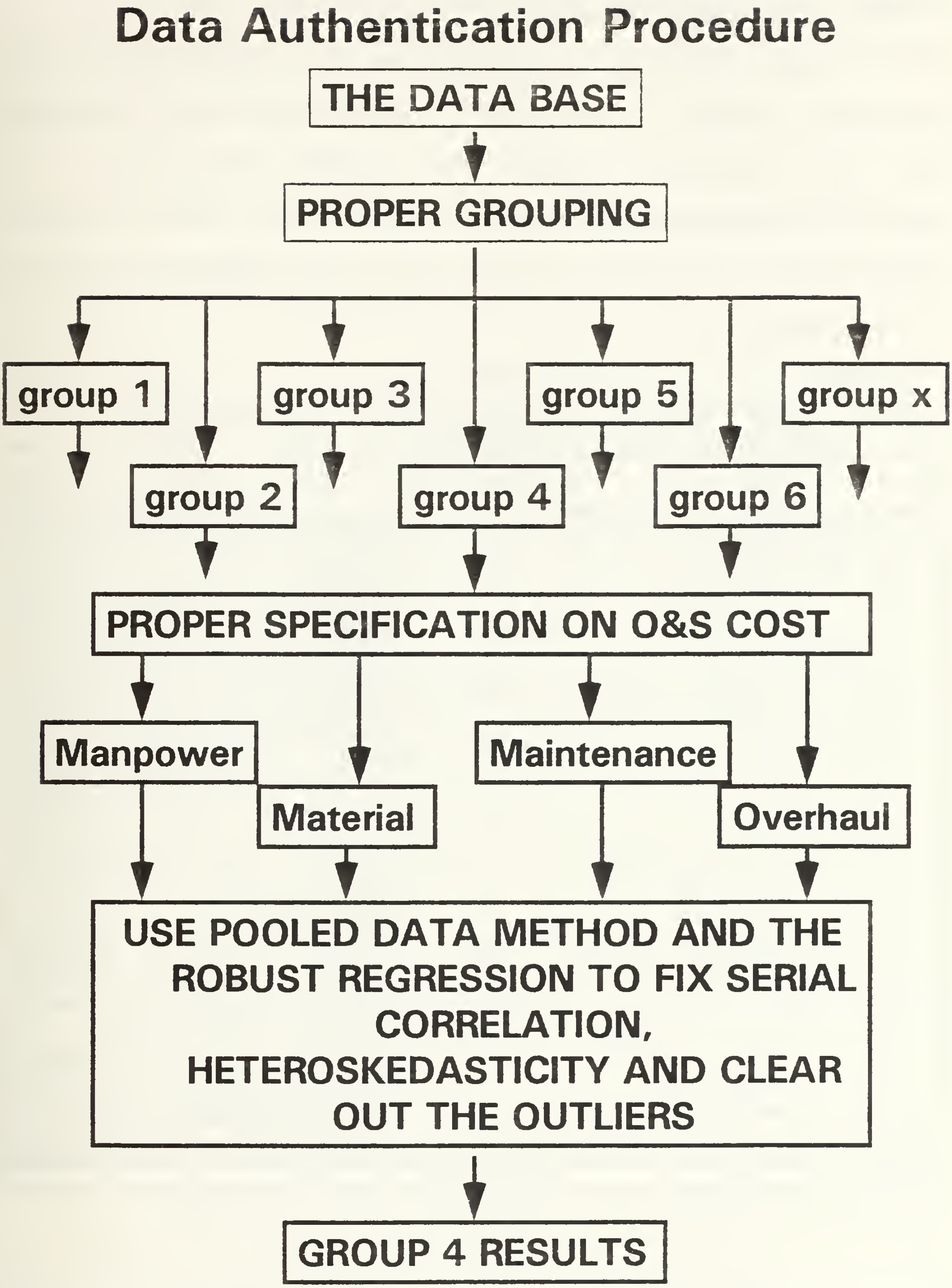
Data Authentication Procedure
THE DATA BASE
PROPER GROUPING
group 1
group 2
group 3
group 4
group 5
group 6
group x
PROPER SPECIFICATION ON O&S COST
Manpower
Material
Maintenance
Overhaul
USE POOLED DATA METHOD AND THE ROBUST REGRESSION TO FIX SERIAL CORRELATION, HETEROSKEDASTICITY AND CLEAR OUT THE OUTLIERS
GROUP 4 RESULTS

Figure 1: VAMOSC-SHIPS combined database authentication procedure flow chart.

1. **Grouping the data**

Ku Shin's study subdivided four traditional ship groups into eleven sub-groups[7]. These traditional groupings are: (1) auxiliary ships, (2) surface combatants, (3) amphibious warfare ships, and (4) submarines. Table 1 from Ku Shin's report (reproduced below) shows the composition of the 11 groupings.

TABLE 1
PREVIOUS GROUPING OF THE SHIPS FROM THE "MODERNIZING AND OPERATING THE MILITARY CAPITAL STOCK" REPORT

Group	Ship Type	# of Obs.	# of Ships		Size (ton)	Years of Service	Acq. Cost (FY 1992 $1,000)
1	Auxiliary Ships: AD, AE, AFS, AGF, AGSS, AO, AOE, AOR, AR, ARS, AS, ASR, ATF, ATS, AVT	762	80	Maximum	52,300	[illegible]	106,800
				Average	[illegible]	28	16,800
				Minimum	1,640	9	1,600
2	Battleships: BB	18	4	Maximum		48	28,300
				Average	58,000	48	26,100
				Minimum		47	22,000
3	Cruisers, Aircraft Carriers: CG, CV	311	38	Maximum	81,773	46	154,400
				Average	27,677	25	61,200
				Minimum	8,065	[illegible]	11,900
4	Nuclear Cruisers and Aircraft Carriers: CGN, CVN	130	14	Maximum	91,487	30	530,100
				Average	35,665	19	92,000
				Minimum	6,888	5	35,800
5	Destroyers: DD, DDG	672	57	Maximum	8,300	[illegible]	253,700
				Average	6,381	[illegible]	58,600
				Minimum	3,960	32	32,200
6	Frigates: FF, FFG	810	71	Maximum	4,200	[illegible]	123,600
				Average	3,472	17	50,600
				Minimum	2,650	3	24,300
7	Amphibious Warfare Ships: LCC, LHA, LHD, LKA, LPD, LPH, LSD, LST	576	59	Maximum	39,300	[illegible]	17,200
				Average	15,516	[illegible]	40,100
				Minimum	8,450	[illegible]	[illegible]
8	Mine Warfare Ships: MCM, MSO	31	5	Maximum	1,312	[illegible]	3166,500
				Average	828	32	79,700
				Minimum	735	[illegible]	60,900
9	Patrol Combatants: PHM	48	6	Maximum		14	
				Average	239.6	10	
				Minimum		8	
10	Submarines: SSAG, SS	51	2	Maximum	3,650	39	391,500
				Average	2,453	32	146,200
				Minimum	930	[illegible]	55,600
11	Nuclear Submarines: SSBN, SSN	1191	122	Maximum	18,700	36	[illegible]
				Average	6,802	19	647,427
				Minimum	2,360	3	323,252
Total		4752	458				

---

[7] In Ku Shin's report, "Historical data trends were constructed for four ship categories: ...."

The basis for these 11 groupings is similar operational tempo. But ship sizes vary widely within these groupings. For instance, ships sizes in Group 1 vary from 1,640 to 52,500 tons and ships in Group 4 vary in size from 6,888 to 91,487 tons. Also, while SSBNs and SSNs are similar in their nuclear propulsion systems, they have very different missions. Since the VAMOSC-SHIPS data provides a level of detail data down to individual ships, we expanded the grouping to a deeper "TYPE" level. Grouping ships by type arranges ships by similar operational tempo but with a narrower range of tonnages. Certain types, such as AGs, AGDSs, AGFs, and AGSSs, with only a few ships do not provide enough observations for statistical analysis and others, such as SS, AR, ATF and BB, are obsolete or scheduled for decommissioning. This research will focus on only the following combatant ships: Guided Missile Cruisers (CGs), Nuclear Guided Missile Cruisers (CGNs), Aircraft Carriers (CVs), Nuclear Aircraft Carriers (CVNs), Destroyers (DDs), Guided Missile Destroyers (DDGs), Frigates (FFs), Guided Missile Frigates (FFGs), Nuclear Ballistic Missile Submarines (SSBNs) and Nuclear Submarines (SSNs).

2. Specification on different subcategories of the O&S cost

Before proceeding with the specification of each O&S cost field, the database was analyzed to determine the number of missing values which will reduce the number of valid observations for our analyses. Figure 2 compares missing values and the remaining numbers of observations for several useful variables.

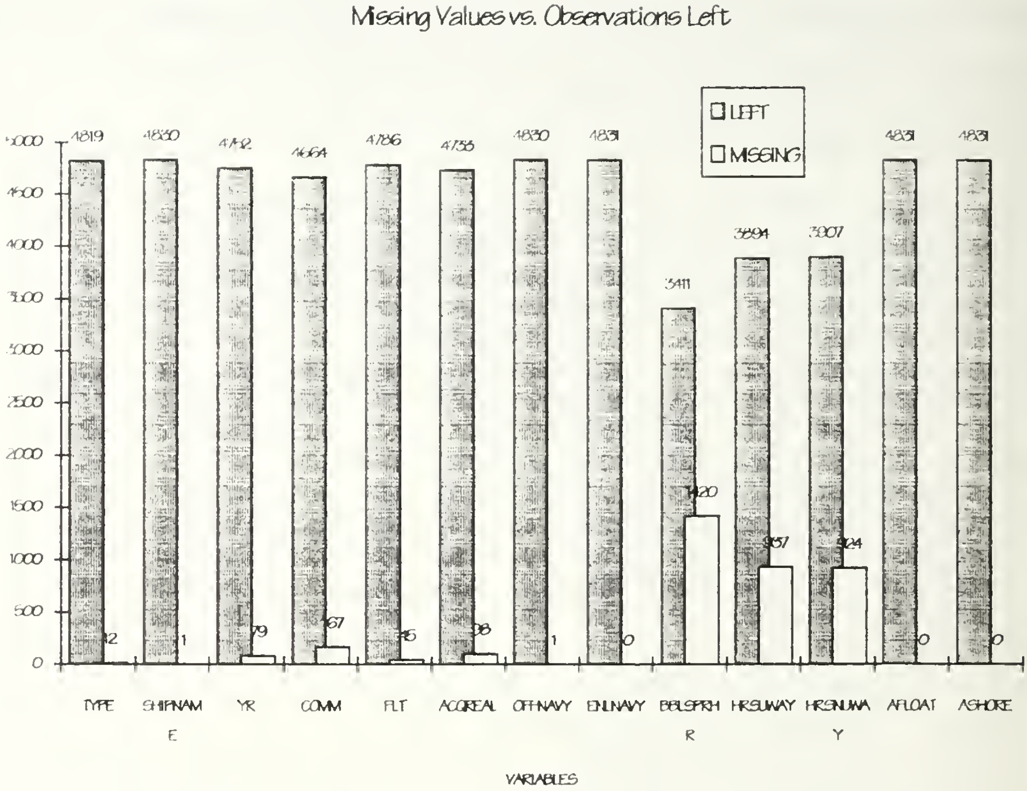

Figure 2: Missing values vs. observations left.

Most of the missing values are truly missing. BBLSPRHR (barrels of fuel per steaming hour), HRSUWAY (steaming hours underway), and HRSNUWAY (steaming hours not underway) are missing values for several types of ships because the data is classified and therefore not available. Other than these three variables, the database has a rather small proportion of missing values.

The elements and sub-elements of the VAMOSC-SHIPS database were categorized into four subcategories: (1)

manpower, (2) material, (3) maintenance, and (4) overhaul. For each field, an accounting-oriented equation was specified for data authentication.

The definitions and justifications for the four categories of dependent and independent variables are provided below.

a. *Manpower*

In order to most closely duplicate the original calculations made to enter values into the database, temporary additional duty (TAD; sub-element 1.1.2) was eliminated from sub-element 1.1 leaving only manpower (sub-element 1.1.1) as the dependent variable. The definition for manpower (MP) provided by the VAMOSC-SHIPS book is:

> Cost of the services of all active duty Navy personnel assigned to the ship as reported by Defense Finance and Accounting Service - Cleveland Center from the Joint Uniform Military Pay System (JUMPS). This includes base pay, allowances, other entitlements and government contributions to FICA and SGLI. This element does not include the indirect costs of trainees, unassigned personnel, permanent change of station, prisoners, patients, etc.[Ref 1:P. A-3]

The number of officers (OFFNAVY[8]) and enlistees (ENLNAVY[9]) assigned to each ship were the independent variables. The coefficients of these variables would then represent the average annual pay for officers and enlistees respectively. The equation for the manpower regression is as follows:

---

[9] Refer to Appendix A, sub-element 1.1.1.3, ENLISTED MANPOWER.

$$MP = \alpha_0 + \alpha_1 OFFNAVY + \alpha_2 ENLNAVY + \epsilon \tag{1}$$

All independent variables should have a positive sign. We can reasonably say that the value for α_1 should be greater than that of α_2 because officers are paid more than enlistees. The relationship of the independent variables is additive, so the values for both dependent variable and independent variables should be arithmetic from the raw data and not logarithmic.

b. Material

Material (MAT; sub-element 1.2) is defined as:

> Cost of all materials utilized or consumed by the ship with the exception of materials utilized in the Intermediate and Depot level maintenance effort which are reported under elements 2.0 and 3.0.[Ref. 4:P. A-8]

Petroleum and fuel burnt comprise most of the material consumed by ships. Since all depot level maintenance is not included in this sub-element, then it is assumed that material and consumables used are proportional to the fuel burnt. The product of steaming hours underway (HRSUWAY) and the barrels of fuel per steaming hour (BBLSPRHR) is used to represent fuel burnt. Given the multiplicative relationship between the HRSUWAY and BBLSPRHR, the regression equation should look like the following:

$$MAT = e^{\beta_0} HRSUWAY^{\beta_1} BBLSPRHR^{\beta_2} e^{\epsilon} \tag{2}$$

Here e^{β_0} is equal to the unit price of the fuel. After taking natural logarithm of both sides of this regression, the regression equation will look like the following:

$$\ln(MAT) = \beta_0 + \beta_1 \ln(HRSUWAY) + \beta_2 \ln(BBLSPRHR) + \epsilon \quad (3)$$

If the dependent variable contains only the cost of fuel burnt, then we should expect β_1 and β_2 to be the value 1 and the β_0 = ln(unit price of the fuel). Because sub-element 1.2 contains sub-elements other than fuel, we expect that both β_1 and β_2 will capture some of these costs. The β that captures more of these costs other than fuel will have a coefficient greater than 1 and the other will have a coefficient less than 1.

c. Maintenance

Maintenance (MH) contains all the sub-elements under element 2.0. It is defined as:

> Cost of material and labor expended by a tender repair ship, or equivalent ashore or afloat Intermediate Maintenance Activity (IMA) in the repair and alteration of other vessels. Regular ship overhaul, non-scheduled ship repair and fleet modernization costs are included in element 3.0.[Ref. 4:P. A-34]

The element contains four sub-elements which are: (1) afloat maintenance labor, (2) ashore maintenance labor, (3) material, and (4) commercial industrial services. Among the definitions for these sub-elements, the definition for commercial industrial services is critical to our accounting-oriented regression on maintenance. The definition of commercial industrial services is:

> Cost for accomplishing afloat and ashore intermediate maintenance actions by private contractors due to workload

limitations at the Intermediate Maintenance Activities (IMAs).[Ref. 4:P. A-42]

This definition reveals that the Navy uses commercial industrial services to perform intermediate maintenance actions only after first saturating its afloat maintenance actions capacity and then its ashore maintenance actions capacity. If we use afloat maintenance hours (AFLOAT) and ashore maintenance hours (ASHORE) as the independent variables in the linear regression on maintenance cost, the coefficients should be the hourly average wage plus whatever is captured from the commercial industrial services. But, the commercial industrial services should be absorbed mostly by ashore maintenance hours since commercial industrial services costs only occur after the ashore maintenance workload is full. The equation that expresses these relationships is the following:

$$MH = \gamma_0 + \gamma_1 AFLOAT + \gamma_2 ASHORE + \epsilon \qquad \textbf{(4)}$$

The relationship between AFLOAT and ASHORE is additive and hence the linear formation of the equation. Because the quantity for commercial industrial service is relatively small, both the coefficients for AFLOAT and ASHORE should be close to the \$17.83 hourly E-6 wage[10]. But, γ_2 should be greater than γ_1 for the aforementioned reasons.

d. Overhaul

Element 3.0 is the direct depot maintenance and it contains: (1) scheduled ship overhaul (OVERHAUL), (2) non-scheduled ship repairs, (3) fleet modernization, and (4) other depot maintenance. Since non-scheduled ship repairs and fleet modernization are atypical overhaul operations, as previously discussed, they will not be relevant to this analysis. And for accounting-oriented regression, "other depot" costs are also ignored because of their relatively insignificant amounts. Theoretically, scheduled ship overhauls should be a function of accumulated steaming hours since the previous engine overhaul and accumulated hours since the previous ship body overhaul. This will be a structural regression rather than an accounting-oriented regression. Since the exact overhaul maintenance rules for different types of ships are unknown[11], and accumulated steaming hours and the length of period between overhauls are equally uncertain and different, it is assumed that whenever the engine stopped running there was an opportunity to perform an overhaul and one was performed. Although overhauls do not necessarily have to be performed with engines stopped, this is usually the case. Engine hours not steaming (HRSNOWAY) is the remaining hours after steaming hours underway (HRSUWAY) and steaming hours not underway (HRSNUWAY) have been deducted from total annual hours (8760 hours):

---

[10] In VAMOSC-SHIPS, there is a note under the sub-elements of afloat and ashore maintenance cost saying "Analysis conducted during the VAMOSC-SHIPS study indicated that an E-6 was the average rating performing IMA maintenance. The Composite Standard Rate for an E-6 is input to the VAMOSC-SHIPS MIS from the most current NAVCOMPT Notice 7041."

[11] Use of standard overhaul costs for different size overhauls to form dummy variables could be one method, but these would be artificial standards. In addition, extraneous regressions would be performed on the overhaul costs.

$$HRSNOWAY = 8760 - HRSUWAY - HRSNUWAY \quad \textbf{(5)}$$

Another factor to be considered is the age of the ship. This variable made the equation not an accounting oriented regression. The AGE variable is introduced to account for the 1985 change in the Navy's overhaul policy. Quoting from the section in ***Estimating Operating and Support Costs of Military Forces***, concerning ship overhauls:

> Two things are noticeable: (1) . . . (2) the number of overhauls per year has been decreasing, most obviously in 1986 and 1987. This decrease is due to a change in Navy policy to increase the time between overhauls.[Ref. 2:P. 12]

As the age of a ship increased, the number of overhauls decreased, reducing overhaul costs and reducing the number of engine shut down hours. The overhaul regression equation should be a log-linear format because the variable AGE should not be logged. The equation should appear as follows:

$$\ln(OVERHAUL) = \theta_0 + \theta_1 \ln(HRSNOWAY) + \theta_2 AGE + \epsilon \quad (6)$$

The coefficient for HRSNOWAY represents the percentage of overhaul cost change for a one percent increase in engine shut down hours. The coefficient for AGE represents the percentage change of overhaul cost for a one year increase in fiscal year of the data year.

3. Robust regression and outlier detection

With over one hundred variables in each observation and a total of 4831 observations, it is entirely plausible that typographical errors or other similar errors occurred during data entry. Because multivariate Ordinary Least Squares/(OLS) linear regression uses the method of minimizing the sum of squares of actual less residuals, it gives undue weight to outlying values ("outliers"). Usually an outlier has a large residual and after squaring the residual, its statistical influence becomes even larger. Robust regression is introduced as a useful method to compare the outlier affected OLS outcome with an unaffected regression outcome. Properly using the criteria given in the robust regression could provide a relationship of the targeted data untainted by outliers. Unfortunately, this method is not popularly used and therefore is not supported in the SAS software used in this study. Although prohibited in applying this method in this study, use of the robust regression method is mentioned in order to suggest to follow-on researchers the possible benefits of its use in further authenticating this database.

4. Serial correlation and heteroskedasticity

Serial correlation and heteroskedastic variation are two potential problems involved in performing linear regression on this pooled database containing all the Navy's ships from 1981 to 1990. If we deal only with serial correlation, we will have to regress on individual ship or on annual average of a group of ships and will potentially lose the ability to deal with heteroskedasticity. If we deal with only heteroskedasticity, we will have to regress on cross sectional data annually or average data of each type and potentially will lose the ability to deal with the serial correlation. Fortunately, there is a method found in a book, ***Elements of Econometrics*** by Jan Kmenta[Ref. 5]. The cross-sectionally heteroskedastic and timewise autoregressive model deals with these two problems simultaneously. Provided below is the relevant part of the model in order to illustrate the procedure used for all regressions in this study:

> Concerning the time-series data, one usually suspects that the disturbances are autoregressive though not necessarily heteroskedastic. When dealing with pooled cross-section and time-series data, we may combine these assumptions and adopt a ***cross-sectionally heteroskedastic and timewise autoregressive method.*** The particular characterization of this model is
>
> (12.22) $E(\varepsilon_{it}^2) = \rho_i^2$ (*heteroskedasticity*),
>
> (12.23) $E(\varepsilon_{it}\varepsilon_{jt}) = 0 \quad (i \neq j)$ (*cross-sectional independence*),
>
> (12.24) $\varepsilon_{it} = \rho_i \varepsilon_{i,t-1} + \mu_{it}$ (*autoregression*),
>
> where

$$\mu_{it} \sim N(0, \rho_{ui}),$$

$$\varepsilon_{i1} \sim N\left(\frac{\rho_{ui}}{1 - \rho_i}\right),$$

and

$$E(\varepsilon_{i,t-1}\mu_{jt}) = 0 \quad \textit{for all } i, j.$$

Note that in this model we allow the value of the parameter ρ to vary from one cross-sectional unit to another. From these specifications we deduce

$$E(\varepsilon_{it}\varepsilon_{is}) = \rho^{t-s}\sigma_i \quad (t \geq s),$$
$$E(\varepsilon_{it}\varepsilon_{js}) = 0 \quad (i \neq j).$$

By making the appropriate substitution, we find that for this model

$$(12.25) \quad \Omega = \begin{bmatrix} \rho_1^2 V_1 & 0 & \cdots & 0 \\ 0 & \rho_2^2 V_2 & \cdots & 0 \\ \vdots & \vdots & & \vdots \\ 0 & 0 & \cdots & \rho_N^2 V_N \end{bmatrix},$$

where

$$V_i = \begin{bmatrix} 1 & \rho_i & \rho_i^2 & \cdots & \rho_i^{T-1} \\ \rho_i & 1 & \rho_i & \cdots & \rho_i^{T-2} \\ \vdots & \vdots & \vdots & & \vdots \\ \rho_i^{T-1} & \rho_i^{T-2} & \rho_i^{T-3} & \cdots & 1 \end{bmatrix}$$

and each of the 0's represents a (T X T) matrix of zeros.

To find consistent estimates of the elements of (12.25), we can proceed in the following way. First, we apply the ordinary least squares method to all N X T observations. The resulting estimates of the regression coefficients are unbiased and consistent, and can be used to calculate the regression residuals e_{it}. From these residuals, we can obtain consistent estimates of ρ_i, say, ρ_i-hat, by

(12.26)
$$\hat{\rho}_i = \frac{\sum e_{it} e_{i,t-1}}{\sum e_{i,t-1}^2} \qquad (t=2,3,\ldots T).$$

When T is small, however, ρ_i-hat may exceed one in absolute value. To avoid this possibility, we may estimate ρ_i by the sample coefficient of correlation between e_{it} and $e_{i,t-1}$, i.e., by

$$\hat{\rho}_i = \frac{\sum e_{it} e_{i,t-1}}{\sqrt{\sum e_{it}}\sqrt{\sum e_{i,t-1}^2}} \qquad (t=2,3,\ldots T).$$

This is also a consistent estimator of ρ_i and its value is confined to the interval from -1 to +1 for any sample size.

Next, we use the ρ_i-hat's to transform the observations in accordance with (8.61); that is, we form

(12.27)
$$Y_{it}^* = \beta_1 X_{it,1}^* + \beta_2 X_{it,2}^* + \cdots + \beta_K X_{it,K}^* + \mu_{it}^*$$

where

$$Y_{it}^* = \sqrt{1-\hat{\rho}_i^2}\; Y_{it} \qquad \text{for } t=1,$$
$$Y_{it}^* = Y_{it} - \hat{\rho}_i Y_{i,t-1} \qquad \text{for } t=2,3,\ldots,T,$$

and

$$X_{it,k}^* = \sqrt{1-\hat{\rho}_i^2}\; X_{it,k} \qquad \text{for } t=1,$$
$$X_{it,k}^* = X_{it,k} - \hat{\rho}_i X_{i,t-1,k} \qquad \text{for } t=2,3,\ldots,T,$$
$$k=1,2,\ldots,K,$$
$$i=1,2,\ldots,N.$$

The purpose here is to estimate σ_i^2 from observations that are, at least asymptotically, nonautoregressive since estimated variances based on autoregressive disturbances are, in general, biased. To this end, we can apply the ordinary least squares method to (12.27) for which we have NT observations. The resulting regression residuals, say, μ_{it}*-hat, can be used to estimate the variances of μ_{it} (i.e., σ_{ui}^2) by

(12.28) $$s_{ui}^2 = \frac{1}{T-K} \sum_{t=1}^{T} \hat{\mu}_{it}^{*2}.$$

Since $\sigma_{ui}^2 = \sigma_i^2 (1 - \rho_i^2)$, it follows that σ_i^2 can be estimated by

(12.29) $$s_i^2 = \frac{s_{ui}^2}{1-\hat{\rho}_i^2}$$

Since $\hat{\rho}_i$ is a consistent estimator of ρ_i and s_{ui}^2 is a consistent estimator of σ_{ui}^2, s_i^2 is a consistent estimator of σ_i^2.

Having obtained consistent estimators of ρ_i and σ_i^2, we have completed the task of deriving consistent estimators of the elements of Ω. By substituting for $\hat{\Omega}$ in (12.20) and (12.21a), we obtain the desired estimates of the regression coefficients and of their variances. Iteration of this procedure until convergence is reached will lead to maximum likelihood estimates.

Since the evaluation of (12.20) and (12.21a) is quite burdensome computationally, we may subject the observations to a double transformation - one transformation designed to remove autoregression and the other to remove heteroskedasticity - and then use the ordinary least squares method on the transformed data. The autoregressive transformation is described by (12.27), so that we only have to worry about the transformation to remove heteroskedasticity. This transformation can be carried out by dividing both sides of (12.27) by s_{ui} obtained from (12.28), which leads to

(12.30) $$Y_{it}^{**} = \beta_1 X_{it,1}^{**} + \beta_2 X_{it,2}^{**} + \ldots + \beta_K X_{it,K}^{**} + \mu_{it}^{**},$$

where

$$Y_{it}^{**} = \frac{Y_{it}^{*}}{s_{ui}}$$

$$X_{it,k}^{**} = \frac{X_{it,k}^{*}}{s_{ui}} \qquad (k=1,2,\ldots,K),$$

$$\mu_{it}^{**} = \frac{\mu_{it}^{*}}{s_{ui}}$$

$$t=1,2,\ldots,T, \qquad i=1,2,\ldots,N.$$

> The disturbance μ_{it}^{**} is asymptotically nonautoregressive and homoskedastic. The equation (12.30) can then be estimated by the ordinary least squares method, utilizing all of the NT pooled observations. The resulting estimates will be the same as those obtained by the two-stage formulas (12.20) and (12.21a).[Ref. 5:P. 618-620]

The aforementioned model is the mathematical side of the method. Before this method can be used, it must be expressed in a SAS program that can do exactly the same thing that the model asked for. The model is useful in authenticating data in four subcategories of O&S costs: manpower, material, maintenance, and overhaul. Appendix C provides the basic SAS program to perform the functions described by the cross-sectionally heteroskedastic and timewise autoregressive model. The other three programs are similar with the exception of changes to specific dependent and independent variables.

C. DATA AUTHENTICATION REGRESSION RESULTS AND INTERPRETATIONS

After developing the data authentication procedure and writing the programs for regression, analysis on the four subcategories provided by the VAMOSC-SHIPS database can be performed. The following four sections are the results analyses of these regressions.

1. Manpower Costs

Table 2 is the final result of manpower accounting oriented regression. The intercepts of each regression are not shown but all are close to zero and significant at the 95% level.

TABLE 2
MANPOWER DATA AUTHENTICATION FINAL RESULTS FOR THE TEN SELECTED TYPES OF THE NAVY'S SHIPS

	F value	R^2	OFFNAVY	T	ENLNAVY	T
CG(218)	4732	0.9776	73460	6.771	18362	23.528
CGN(89)	1166	0.9636	63606	4.021	19364	14.484
CV(87)	1886	0.9777	86510	4.994	15837	16.247
CVN(41)	331	0.9429	28936	0.810	17618	8.350
DD(307)	6366	0.9765	46733	4.826	19364	27.222
DDG(353)	9493	0.9818	33334	6.474	20284	54.728
FF(496)	10703	0.9774	50746	7.775	19371	38.555
FFG(317)	11265	0.9862	66809	9.220	19627	34.548
SSBN(344)	20328	0.9916	69350	11.675	24619	38.593
SSN(888)	34936	0.9875	25868	6.434	28338	58.222

* SOURCE: regression performed by author.

Some highlights of the outcomes of these regressions:

- The OFFNAVY coefficients represent the annual pay for officers and the ENLNAVY coefficients represent the annual pay for enlistees. In most cases, the expected relationship - that officers were paid higher than enlistees - is true. Only for type SSN is the enlistee coefficient larger than the officers.

- The annual variation could be related to the different ratios of officers to enlistees, different bonuses for different ships, etc. For example, an aircraft carrier has more high ranking officers and pilots receiving flight pay, so the coefficient of OFFNAVY which represents the average officer annual pay should be higher than for certain other ships. Also if a ship has more married crew members, the allowances may change the average annual pay and result in different coefficients in the regression.

- The shaded cells contain uninterpretable outputs. Except that the type SSN has lower officer pay than enlistees, type CVN has an insignificant OFFNAVY coefficient which is also too low and the coefficient of OFFNAVY for type DDG is too low as well.

- After manually examining the manpower cost for type SSN, the SSN manpower data was determined to be unreliable. It was discovered that for some consecutive years with identical numbers of enlistees and different number of officers, the cost for the year with more officers is much less than years with less officers.

2. Material Costs

TABLE 3
MATERIAL DATA AUTHENTICATION FINAL RESULTS FOR THE TEN SELECTED TYPES OF THE NAVY'S SHIPS

	F value		HRSUWAY	T	BBLSPRHR	T
CG(218)	37393	0.9971	0.6643	14.218	3.1893	28.763
CGN(89)	2635	0.9677	1.8526	51.335	N/A	N/A
CV(87)	4319	0.9901	0.6927	8.464	2.4119	17.661
CVN(41)	37	0.4758	1.0041	6.108	N/A	N/A
DD(307)	73086	0.9979	0.8940	20.998	2.6633	25.767
DDG(353)	44962	0.9961	0.8596	24.601	2.7466	32.966
FF(496)	78281	0.9968	0.8928	28.872	2.9838	33.746
FFG(317)	109437	0.9986	1.1531	28.060	2.4000	18.528
SSBN(344)	74	0.1771	0.6709	8.649	N/A	N/A
SSN(888)	180	0.1686	0.6227	13.448	N/A	N/A

* SOURCE: regression performed by author.

A few points relevant to Table 3 follow:

- Because this is a double log regression, the HRSUWAY coefficient represents the percentage change of material cost when there is a one percent increase in steaming hours, and the coefficient of BBLSPRHR represents the percentage change of material cost when there is one percent increase in barrels of fuel used each steaming hour.

- Since the effect of the absence of BBLSPRHR data for nuclear powered ships like CGN, CVN, SSBN and SSN (due to security requirements) upon the coefficients of other independent variables is uncertain, the regression analysis results for nuclear powered ships (shaded rows) should be disregarded.

- For the other regressions, we find that the coefficients for BBLSPRHR are much larger than those for HRSUWAY. One possible explanation for this result is that when ship sail at higher speeds, fuel consumption per steaming hour increases and in turn fuel costs per steaming hour rise as well. Higher sailing speeds also cause repairs to be required sooner. Simulated combat conditions (such as during exercises) may require higher sailing speeds and also require increased use of ammunition. These costs are captured by higher BBLSPRHR. It therefore is understandable that the effect of HRSUWAY upon predicting O&S costs is less than the effect of BBLSPRHR.

3. Maintenance Costs

TABLE 4
MAINTENANCE DATA AUTHENTICATION FINAL RESULTS FOR THE TEN SELECTED TYPES OF THE NAVY'S SHIPS

	F value	R^2	AFLOAT	T	ASHORE	T
CG(218)	784	0.8783	18.4171	35.307	20.5953	19.981
CGN(89)	121	0.7330	16.7326	13.273	19.7223	8.771
CV(87)	17	0.2785	14.1762	2.708	16.0105	5.535
CVN(41)	0.1	-0.0466	-0.4754	-0.017	-6.0699	-0.467
DD(307)	1003	0.8676	18.1340	30.134	20.6254	35.519
DDG(353)	1357	0.8851	18.3317	41.978	19.9954	35.591
FF(496)	1884	0.8839	17.8069	49.408	21.5226	43.625
FFG(317)	182	0.5347	17.1456	7.321	33.1605	18.351
SSBN(344)	7970	0.9789	18.9543	117.303	19.3935	70.122
SSN(888)	33124	0.9868	18.9562	203.783	18.6931	190.723

* SOURCE: regression performed by author

Some points relevant to Table 4 are:

- The AFLOAT coefficient represents the hourly wage for maintenance on board the ship and the possible attached commercial maintenance cost; the ASHORE coefficient represents the hourly wage for maintenance at a shore depot and the possible attached commercial maintenance cost.

- According to VAMOSC-SHIPS, commercial maintenance is used only if the Navy's maintenance capacity is full. Most commercial maintenance cost should be attached to ASHORE maintenance hours. Table 4 shows that ASHORE coefficients are greater than the AFLOAT coefficients.

- The small adjusted R^2 and F values for CVNs, especially, as well as for CVs reflects fundamental differences in maintenance policies for these two classes of ships. The maintenance system policies for CVs and CVNs are dramatically different from other ship types. For example, 83% of CVN maintenance costs go to commercial maintenance with similar circumstances for CVs. This does not seem unusual given the enormous size and importance of these ships.

4. Overhaul Costs

TABLE 5
OVERHAUL DATA AUTHENTICATION FINAL RESULTS FOR THE TEN SELECTED TYPES OF THE NAVY'S SHIPS

	F value	R^2	NOWAY	T	AGE	T
CG(218)	561	0.8377	0.7802	26.723	0.3145	6.307
CGN(89)	53	0.5459	2.1651	8.837	-0.0369	-0.453
CV(87)	850	0.9518	2.0619	20.498	-0.0585	-1.252
CVN(41)	215	0.9149	1.1555	6.648	0.2166	4.561
DD(307)	45	0.2253	1.2443	7.841	0.1912	1.660
DDG(353)	113	0.3902	2.1220	11.368	-0.1322	-2.383
FF(496)	218	0.4676	2.1259	16.366	-0.2802	-4.913
FFG(317)	98	0.3808	0.6243	7.511	0.3649	6.391
SSBN(344)	65	0.2742	1.6773	7.411	-0.1603	-1.544
SSN(888)	481	0.5198	1.4578	27.612	0.0980	3.472

* SOURCE: regression performed by author

The points we would like to make concerning Table 5 are:

- The NOWAY coefficient represents the percentage change in overhaul costs given a one percent increase in engine shut down hours, and the AGE coefficient represents the percentage change in overhaul costs given a one year change in service year.

- The coefficients for engine shut down hours are significant for all ship types but the coefficients for AGE are not significant for the four shaded ship types. Closer examination of the VAMOSC-SHIPS overhaul and age data reveals that ship types with a higher proportion of newer ships have positively significant AGE coefficients and ship types with a lower proportion of newer ships have negatively significant AGE coefficients. Ship types with insignificant AGE coefficients have close to an even ratio of newer and older ships.

- *Estimating Operating and Support Costs of Military Forces* discusses a change to Navy overhaul policy in 1985. The policy change has slowed the steady rise of newly commissioned ship overhaul schedules by stretching the time period between overhauls. The effect on older ships has been to cause a decrease from steady state overhaul costs due to the lengthened interval between overhauls. A similar effect is experienced by middle age ships for the same reason.

One way to address the effect on O&S costs of this overhaul policy change is by classifying each ship as "old", "mid age" and "young" and running a regression to detect any differences. But this will reduce the number of observations after we divide them into three subgroups. Some will have no new ships and some will have no old ships (Appendix D). It is, therefore, better to discuss this effect in an aggregate regression.

D. UNANSWERED SIDE-EFFECTS OF THE OVERHAUL POLICY CHANGE

Because of the Navy's 1985 overhaul policy change, and its possible negative effects on the overhaul regression resulting from varying mixtures of new and old ships among the different ships types, one may ask whether manpower costs, fuel and material consumption costs, or maintenance costs were affected. And if so, how? Perhaps the overhaul policy change increased ship manpower costs due to fewer overhauls per time period with, perhaps, decreased manpower requirement at the depots. Perhaps fuel and material consumption increased due to fewer engine shut down hours? Perhaps, the policy change resulted in increased maintenance costs in order to compensate for the longer time span between overhauls. In order to investigate these possible side-effects, regressions on the collective dataset were conducted in order to obtain an overview of the entire Navy. This analysis was divided into the same four subcategories used previously. The following sections provide the regression outcome comparisons and analysis.

1. Manpower Costs

To detect potential side-effects of the overhaul policy change on manpower, two regressions were performed. The first one used the same specification as the accounting oriented regression. The second one included a data year (YR) factor, defined as 81,...,90. Table 6 compares the results of these two regressions.

TABLE 6
MANPOWER REGRESSIONS ON ALL OBSERVATIONS WITH AND WITHOUT DATA YEAR AS ADDITIONAL FACTOR

(4645 OBSERVATIONS)	REGRESSION W/O YEAR	REGRESSION WITH YEAR
F VALUE	105316	126071
ADJUSTED R^2	0.9784	0.9879
INTERCEPT	0.450	-9.1522
T	20.581	-23.365
OFFNAVY	101570	102660
T	67.140	67.433
ENLNAVY	16412	16606
T	152.507	165.367
YEAR	-	0.1105
T	-	24.307

* SOURCE: regression performed by author

The newly added variable YEAR is significant but with a very small coefficient value, which appears to represent the real rate of increase in manpower costs. A study of the sign, significance and source of this coefficient is beyond the scope of this report, but is recommended as an area appropriate for further manpower study.

2. Material Costs

TABLE 7
MATERIAL REGRESSIONS ON ALL OBSERVATIONS WITH AND WITHOUT DATA YEAR AS ADDITIONAL FACTOR

(4645 OBSERVATIONS)	REGRESSION W/O YEAR	REGRESSION WITH YEAR
F VALUE	203851	171874
ADJUSTED R^2	0.9887	0.9911
INTERCEPT	0.7168	-0.1054
T	41.320	-0.238
HRSUWAY	1.1122	1.1630
T	72.894	81.684
BBLSPRHR	2.1341	2.0340
T	54.366	55.147
YEAR	-	0.0094
T	-	1.827

* SOURCE: regression performed by author.

Table 7 presents the results of the material cost regressions. For this subcategory, the year factor does not seem to be relevant because the T value is insignificant at the 0.05 level of statistical significance. Also the quantity is very small even it is significant at the 0.10 level. Notice that the intercept changed from 0.7188 to -0.1054 which will be compensated for by the product of the year and its coefficient. This is due to the YEAR variable beginning at 81. The positive coefficient indicates the material costs increase as years increase. Curiously, when the falling price [Ref. 6] of oil products (fuel, petroleum lubricants, etc.) during the period 1981-1986 is considered, the slight increase in the material cost could be an indication of more steaming hours for ships, an average increase in combat mission during these years, a growing inventory of ships or inflation offsetting the decreasing oil price. The specific reason for the coefficient's sign, size and significance is beyond the scope of this study.

3. Maintenance Costs

TABLE 8
MAINTENANCE REGRESSIONS ON ALL OBSERVATIONS WITH AND WITHOUT DATA YEAR AS ADDITIONAL FACTOR

(4645 OBSERVATIONS)	REGRESSION W/O YEAR	REGRESSION WITH YEAR
F VALUE	21196	11184
ADJUSTED R^2	0.9012	0.8784
INTERCEPT	0.2322	-3.5546
T	21.122	-11.005
AFLOAT	18.6879	19.0927
T	156.402	138.523
ASHORE	18.9710	19.3635
T	142.480	127.775
YEAR	-	0.0443
T	-	11.762

* SOURCE: regression performed by author

Table 8 presents the results of the maintenance cost regressions. The YEAR coefficient is positively significant although the magnitude of the value is very small. Also the intercept changed drastically to -3.5648 which will be offset by the product of the calendar year and its coefficients. Again, this is a result of YEAR variable beginning with year 81. The positively significant coefficient means the maintenance cost increased very slowly. 0.443% was the total increase over the ten years from 1981 to 1990. Is it possible that this increase is due to the overhaul policy change? It is hard to tell. It may also be that newer technology requires less maintenance hours (assuming unit price for maintenance remains fairly constant over the ten years), then these slightly increased maintenance costs reflect the growing number of Navy ships during the 1980s. If, on the other hand, maintenance on newer high-technology equipment is more expensive but the number of the maintenance hours remains the same, then increased maintenance unit cost might be the reason for the increase in maintenance costs. If the new technology requires less maintenance hours but at a higher cost per unit, then it is really hard to tell. Once again, this is an area beyond the scope of this study.

4. Overhaul Costs

The overhaul aggregate regression will be slightly different from the previous three regressions because it is assumed the policy change will have different effects on old, mid age and young ships. Age was already one of the independent variables of the equation. Here, AGE is divided into three different categories according to our assumption. Old ships are defined as ships commissioned before 1976. Any ship commissioned in year 1976 through 1980 is defined as a mid age ship. Young ship are defined as ships commissioned in years 1981 through 1990.

A basic assumption concerning overhaul costs is that within five years after commissioning, ships have reached a long term steady state for overhaul costs. Old ships therefore are assumed to have reached long term steady state costs. Because of the overhaul policy change, the overhaul costs for the old ships would only decrease in the data year. Mid age ships could have both increasing and decreasing overhaul costs in the data year because their increasing trend became decreasing when the policy changed, with the net effect being negligible. Young ships would only show increasing overhaul costs because they have not yet reached long term steady state and are experiencing larger and larger overhaul costs according to their pre-1985 or post-1985 overhaul policy schedule. Longer intervals between overhauls in the post-1985 overhaul policy will result in a longer overall time period to reach steady state. The assumption we made is shown graphically in Figure 3.

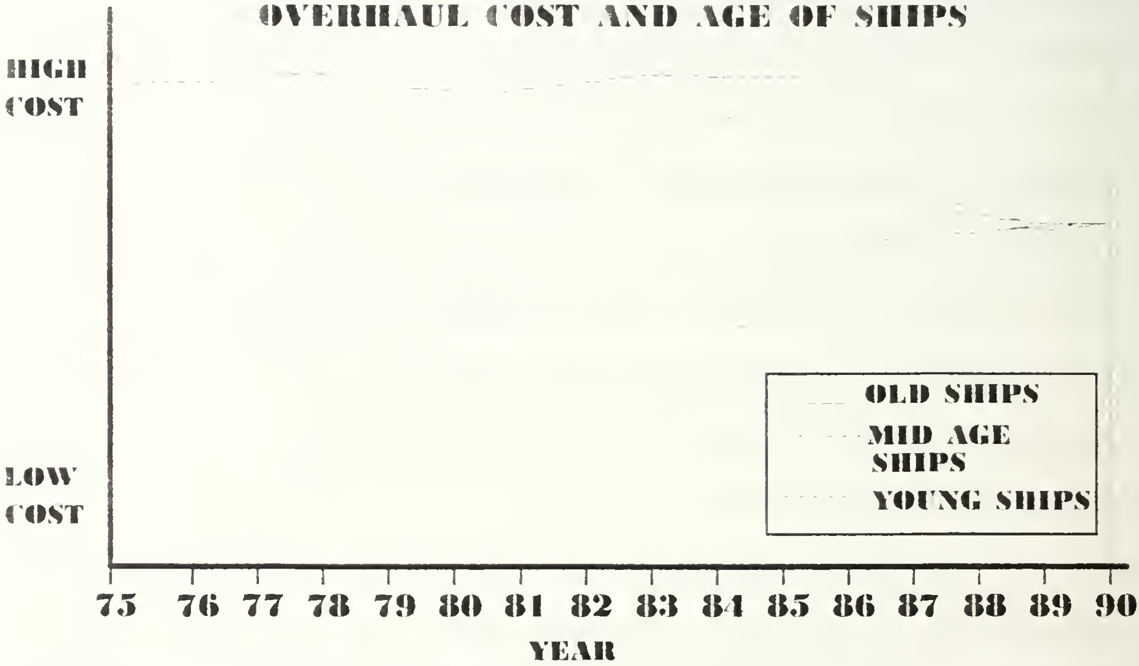

Figure 3: The relationships for old ships, mid age ships and young ship under the changed overhaul cost.

In the regression, the mid age ships is the default since they will have an insignificant positive/negative coefficient. The two dummy variables for the three categories of ships are not enough to show the tendency of the overhaul cost, they only define the different intercept for these categories. In order to show decreasing old ships' overhaul costs and increasing young ships' overhaul costs, it required two dummy slopes to capture the rate of change in overhaul costs for these three categories. When the two dummy variables are equal to zero, the regression will have only one remaining independent variable - HRSNOWAY. Below are the outcomes of the regressions.

TABLE 9
OVERHAUL REGRESSIONS ON ALL OBSERVATIONS WITH AND WITHOUT DATA YEAR AS ADDITIONAL FACTOR

(4645 OBSERVATIONS)	REGRESSION W/O YEAR	REGRESSION WITH YEAR
F VALUE	1428	667
ADJUSTED R^2	0.3807	0.4177
INTERCEPT	-0.1448	-0.0701
T	-4.660	-1.486
HRSNOWAY	1.4180	1.4033
T	53.115	54.992
AGE	0.0106	-
T	1.978	-
OLD	-	2.6039
T	-	5.765
OLDYEAR	-	-0.0303
T	-	-5.755
YOUNG	-	-5.8632
T	-	-4.504
YOUNGYEAR	-	0.0637
T	-	4.260

* SOURCE: regression performed by author

The results are exactly as predicted. The adjusted R^2 increased a bit. The effect of the product of data year and slope coefficient offsetting the intercept still exists in this regression with year considered. Old ships have a significant tendency for decreasing overhaul costs by 0.0303% per year and young ships have a significant increasing tendency for overhaul costs by 0.0637% each year. This same regression was used in Appendix D and was not successful due to the limited number of observations in individual types.

E. SHORT CONCLUSION FOR DATA AUTHENTICATION

Detailed analysis of the database resulted in better understanding of its quality. The following is a brief summary of the findings concerning the quality of the database.

- **Aggregate analysis of the ten ship types should exclude CVNs and SSNs.** CVNs have a different maintenance system from other ship types and the SSN manpower information appears to be systematically scrambled.

- **Missing fuel consumption values are significant only on nuclear ships.** Because there is no BBLSPRHR data available for nuclear ships and HRSUWAY is not present until 1985, we should try to avoid using these variables in aggregate analysis.

- **The change of the policy in year 1985 is important for understanding overhaul cost structure.** The effect of this policy change on three different ship age categories was examined for its influence on overall O&S costs, and it does influence overall O&S Cost.

- **Overall, the database is suitable for further statistical analysis.** Data authentication procedure followed in the first part of this study successfully identified the aberrant CVN maintenance costs and SSN manpower costs. The remaining subcategories and types are suitable for further analysis.

III. AGGREGATE O&S COST ANALYSIS

Base on the data authentication results, it is determined that the database is suitable for further aggregate analysis. The first step in this further analysis is to define O&S costs. Because this is not accounting oriented analysis anymore, it is useful to include as many relevant and suitable VAMOSC-SHIPS sub-elements in this stage of the analysis in order to enlarge the applicability of the results. Therefore, O&S costs shall include all the main and sub-elements of the VAMOSC-SHIPS data except unscheduled repair costs and fleet modernization costs. It is intended that the theoretically correct independent variables will capture as much of the variation in O&S costs as possible. That is to say:

$$\begin{aligned} \textit{O\&S Costs} &= \textit{Total VAMOSC} - \\ &(\textit{Non-scheduled repair costs} \\ &+ \textit{Fleet modernization costs}) \end{aligned} \tag{7}$$

A. POTENTIAL INDEPENDENT VARIABLES

O&S costs includes all costs that are required for daily operations and any non-daily operations that are in support of daily operations. Many factors influence O&S costs, and there exist interrelationships between these factors. For instance, some factors may be sub-factors of others. The following considerations were examined before choosing appropriate independent variables for aggregate multivariate statistical regression analysis.

1. Steaming hours underway (HRSUWAY)

Steaming hours underway of a ship represents a ship's mission or travel frequency. This factor reflects many costs including fuel, oil, ammunition, food and water costs. HRSUWAY, therefore can be expected to have a direct positive relationship with O&S costs.

2. Acquisition cost in real terms (ACQREAL)

The acquisition cost in real terms is a proxy for ship size, equipment, and the weapon systems installed on the ship. Logically, material and labor construction costs grow with the size of the ship. With few exceptions (a smaller, complex, high-tech ship might be more expensive than a larger, simpler ship) larger ships have higher costs to man and operate them as well. The same holds true for the equipment and systems installed. More equipment requires more maintenance and overhaul costs. However, certain types of new equipment may have higher up-front acquisition costs but lower long-run maintenance and overhaul costs.

3. Manpower on board a ship (MANPWR)

The number of personnel on board a ship is also a proxy for ship size and ship equipment. There is likely to be high correlation between MANPWR and ACQREAL. But this variable may capture some factors like operational tempo. Two different type ships with the same tonnage may require more manpower to operate complex weaponry on a combat ship than on a support ship. There also might be different ratios of officers to enlisted on similar size ships. For instance, aircraft carriers have a higher ratio of officers to enlisted than other ships with the same tonnage. Also, ships with the same tonnage as submarines may have lower manpower costs when compared to the high levels of compensation required to man a submarine. More personnel requires increased O&S costs.

4. Fleet of a ship (FLEET)

Two major ship divisions in the U.S. Navy are the Pacific Fleet and Atlantic Fleet. Ships assigned to the Pacific Fleet on average have longer transit routes than Atlantic Fleet ships and therefore have higher steaming hours per year. The higher steaming hours per year requires more maintenance and more frequent engine overhaul cycles resulting in higher O&S costs. This may be affected by the use of maritime forces to implement U.S. foreign policy decisions. Because of different foreign policy decisions, the Atlantic Fleet may, in fact, spend more time underway patrolling Atlantic and Mediterranean waters in order to execute European and Mideast foreign policy than do Pacific fleet ships. The Pacific Fleet ships have extensive transit routes, but once they arrive on station, the ships are likely to spend a great deal more time in port.

5. Engine shut down hours (HRSNOWAY)

Intuitively, this variable will be highly correlated with HRSUWAY. However, this variable may capture variations in overhaul costs related to engine shutdowns. Usually ship engines are not shut down unless the ship will not be getting underway for an extended period of time. Overhaul is one of the possible conditions that will cause the engine to be shut down. Since overhaul costs are a major portion of the total O&S cost, this is an important focus area of O&S cost analysis. Because of the complementary relationship between the HRSNOWAY and HRSUWAY[12], a negative relationship exists between these two variables. If material costs are larger than the overhaul costs, then HRSNOWAY variable could have the wrong sign in a regression model. If overhaul costs are larger than material costs, then the coefficient of HRSUWAY could have a wrong sign in the regression model. If overhaul costs and material costs are about equal, both coefficients for the variables might be insignificant.

6. Data year (YEAR)

The data year variable captures the Navy's overhaul policy change. Based on the results of the accounting oriented analysis, it was discovered that overhaul costs were affected by both data year and commissioning year. Other subcategories would have some minor variation among years.

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[12] Please refer to equation (5) about the calculation of the engine shut down hours.

YEAR should capture any potential policy change that occurred across the data years.

7. Type of ships (NINE DUMMY VARIABLES)

The variables ACQREAL and MANPWR capture different sizes, equipment and operational tempo characteristics of ships. These differences could also be grasped by using dummy variables to represent the different ship type in order to analyze the explicit effects of ship type differences on O&S costs. Individual ships of a particular ship type have basic similarities in tonnage, equipment and operational tempo. One consideration in using dummy variables for ship types in the analysis is that increasing the number of variables will reduce the degrees of freedom in the analysis. However, this is of little consequence in this particular analysis given the number of observations in this dataset. Since the dummy variables for ship type represent more clearly defined variations among similar characteristics than the variables ACQREAL and MANPWR, these variables could provide more useful insight into the analysis of overall O&S costs. But, as was demonstrated in the first part, if analyses were performed separately on the individual selected types of ships, the dummy variables will be useless. To investigate the feasibility of substituting a set of dummy variables for different ship types in place of the independent variables ACQREAL and MANPWR, an initial analysis was done of their correlations. Table 10 shows the regression results obtained using ACQREAL and MANPWR as dependent variables respectively and the set of dummy variable as independent variables:

TABLE 10
REGRESSION RESULTS FOR SUPPORTING THE SET OF SHIP TYPE DUMMY VARIABLES ON REPLACING THE "ACQREAL" AND "MANPWR" VARIABLES

	LOG OF ACQREAL	LOG OF MANPWR
Observations	1994	1994
F values	1877	9597
Adjusted R^2	0.8683	0.9711
Intercept	11.8826	5.5925
T	1010.870	1439.457
CG	1.4354	0.4292
T	66.252	59.940
CGN	1.9860	0.7694
T	63.364	74.270
CV	2.5354	2.3023
T	82.560	226.825
DD	0.7789	0.1499
T	41.641	24.249
DDG	0.9308	0.2669
T	51.079	44.320
FFG	0.4975	-0.2644
T	25.929	-41.690
SSBN	1.6629	0.0647
T	64.406	7.582

* SOURCE: regression performed by author

These regressions support the assertion that the set of dummy variable are highly correlated with ACQREAL and MANPWR and are appropriate substitutes. The statistical regression results support this conclusion.

B. MODEL OF AGGREGATE ANALYSIS

Having discussed all the candidate independent variables, a model for the aggregate analysis will now be discussed. According to the description in last section, the first six variables, HRSUWAY, ACQREAL, MANPWR, FLEET, HRSNOWAY and YEAR could be a set of independent variables covering all aspects that we thought of for estimating the O&S costs. The different ship types could replace the variables ACQREAL and

MANPWR. Figure 4 shows the basic structure assumed on the independent variables and the dependent variable.

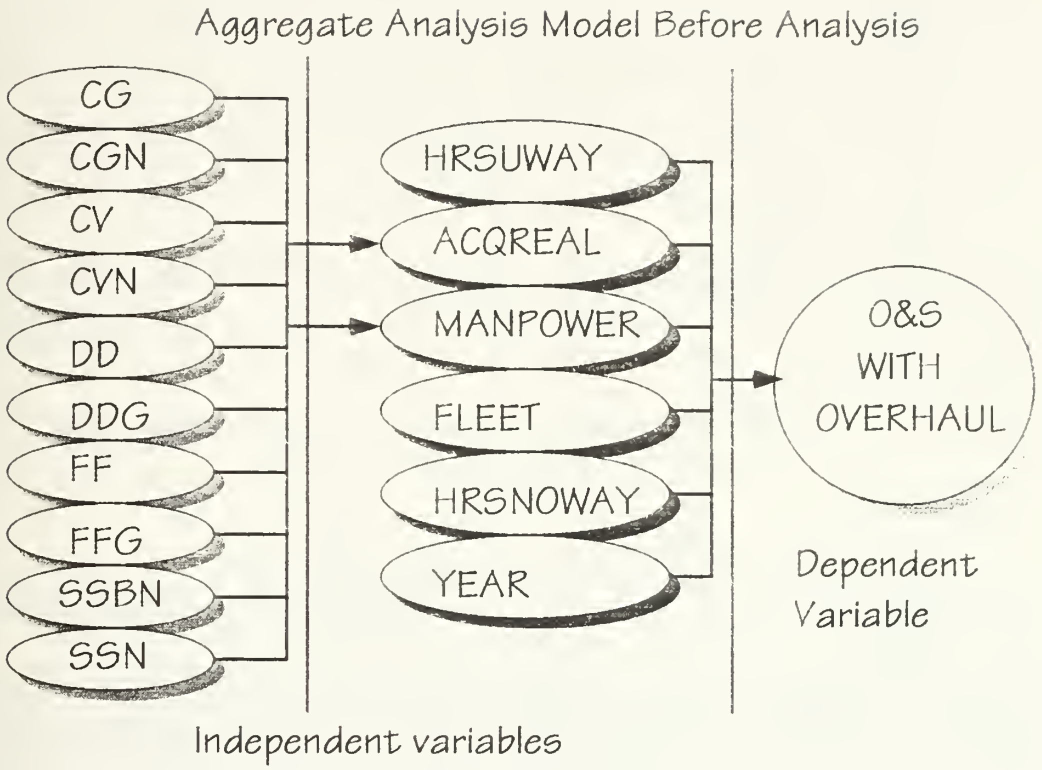

Figure 4: Aggregate analysis model before analysis.

C. REGRESSION EQUATION FORMAT

Because the independent variables included dummy variable(s), the regression would be in log-linear format. The log-linear format is most feasible for the aggregate analysis of O&S cost due to the potential interactions among the independent variables. Hildebrandt and Sze's study, *An Estimation of USAF Aircraft Operating and Support Cost Relations*, discusses the following advantages of applying a log-linear regression model to O&S cost analysis.

Using the data discussed above, we examine the relationship between O&S costs and these types of variables using a log-linear model. Given the nature of

> O&S costs, any regression model is likely to be an approximation of some underlying relationship that is both nonlinear and contains important interactions among the explanatory variables. A log-linear model is a first-order approximation (in the logs) of such a relationship. Its multiplicative functional form (after taking anti-logs) also reflects interaction among the variables. As a result, the effect of a particular explanatory variable on O&S cost depends on the values of the other explanatory variables. This type of interaction would not be obtained in a linear model.
>
> Another advantage of the log-linear model derives from the ease in interpreting the regression coefficients. Since the coefficients of each variable in this model are interpreted as the percentage change in the dependent variable resulting from a 1 percent change in the explanatory variable, the units of measure for the variables become unimportant. As a result, measurement errors that do not affect the growth rates of the variables have no effect on the estimated coefficients of the explanatory variables.
>
> An additional advantage of a log-linear model is that it can reduce a potential problem with heteroskedasticity. For example, if the variance of the error term is correlated with the total number of aircraft in a particular MDS [Mission Design Series], the ordinary least squares estimation technique would yield estimates that are inefficient, although they would remain unbiased. The log-linear model, however, attenuate any correlation between the error term and explanatory variables.[Ref. 3:P. 23]

The aggregate regressions required by this study can likewise be separated into two parts. The first part uses a structural model to perform regression on individual ship types. As we mentioned before, CVN maintenance and SSN manpower subcategories are not suitable for further analysis. However, since the regressions are performed by individual ship type, the abnormal data is isolated in these two types, so the results obtained for the other ship types will remain unaffected. By performing regressions on all ten ship types individually, this may provide support for our previous findings concerning the abnormal quality of these two ship type data subcategories.

The second part will be to perform regression on the remaining eight types collectively using structural variables. By using different combinations of ACQREAL, MANPWR and the various ship type dummy variables it may be possible to establish appropriate relationships between the independent variables and O&S costs.

D. AGGREGATE ANALYSIS ON INDIVIDUAL TYPE

TABLE 11
REGRESSIONS ON O&S COST
(INCLUDING SCHEDULED OVERHAUL COSTS)
(O&S=ELEMENT 1.0+ELEMENT 2.0+SUB-ELEMENT 3.1+ELEMENT 4.0)

	CG (202)	CGN (76)	CV (85)	CVN (29)	DD (296)	DDG (349)	FF (490)	FFG (290)	SSBN (120)	SSN (197)
F value	38997	26263	21729	4644	85047	116948	68754	145067	72191	62259
R^2	0.999	0.999	0.999	0.999	0.999	0.999	0.998	0.999	0.999	0.999
Hrsuway	-0.172	-0.513	-0.127	-0.233	-0.081	-0.127	-0.175	0.033	-0.180	-0.376
T	-10.35	-15.2	-4.763	-3.750	-4.346	-8.585	-11.06	1.799	-5.287	-7.386
Acqreal	0.4245	-0.235	-0.178	0.431	0.344	0.292	0.0173	0.156	-0.177	0.039
T	11.830	-1.78	-1.759	0.765	6.858	6.283	0.459	4.092	-2.324	-0.505
Manpwr	1.386	1.165	2.468	1.965	1.175	1.393	1.486	1.158	-1.811	2.997
T	10.982	2.726	10.017	1.753	6.531	10.478	9.630	14.32	-11.26	4.334
Hrsnoway	0.485	1.887	0.294	-0.207	0.698	0.653	1.044	0.882	3.440	0.545
T	4.248	13.57	1.872	-0.651	7.315	7.557	10.66	11.40	27.71	1.441
Yr	-0.179	-0.016	-0.196	0.006	-0.140	-0.156	-0.140	0.013	-0.349	-0.181
T	-7.473	-0.36	-4.976	0.070	-7.051	-8.804	-9.085	0.627	-3.679	-2.582
Fleet	-0.385	-0.81	0.330	0.086	-0.642	0.015	-0.204	-1.012	N/A	-1.723
T	-2.756	-3.16	1.424	0.136	-5.307	0.129	-2.379	-9.195	N/A	-2.123

* SOURCE: regression performed by author

The regressions shown in Table 11 used the first six variables as the independent variables likely to capture most of the variation in O&S costs. The coefficients for HRSUWAY are the opposite of the hypothesized sign. These opposite signs could be caused by stronger effects of overhaul; the overhaul costs are larger than material costs and HRSUWAY has a complementary relationship with HRSNOWAY. This complementary relationship not only caused HRSUWAY to change sign, it also weakened the effect of HRSNOWAY and made the specification appear to be incorrect. Notice also that all coefficients for CVNs are insignificant and that the manpower coefficient for SSBNs has a negative coefficient.

Since overhaul costs are having a disturbing effect in these regressions, it is better to isolate the correlation between overhaul costs and O&S costs and also between overhaul costs and the other independent variables. As discussed in the data authentication part of the analysis, the sub-element for scheduled overhaul in O&S costs is 3.1, and the independent variables highly correlated with overhaul costs are HRSNOWAY and YEAR. After excluding overhaul costs from O&S costs and removing HRSNOWAY and YEAR from the model, new regressions were performed. Table 12 displays the results of these new regressions.

TABLE 12
O&S COSTS REGRESSIONS
(EXCLUDING SCHEDULED OVERHAUL COSTS)
(O&S=ELEMENT 1.0+ELEMENT 2.0+ELEMENT 4.0)

	CG (202)	CGN (76)	CV (85)	CVN (29)	DD (296)	DDG (349)	FF (490)	FFG (290)	SSBN (120)	SSN (197)
F value	263613	85053	123353	21244	261794	353205	651124	316423	45971	263383
R^2	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
Hrsuway	0.1916	0.089	0.1548	0.0167	0.244	0.1856	0.1918	0.2187	-0.116	0.1009
T	22.50	4.711	10.719	1.072	25.00	23.992	31.201	21.777	-2.828	10.04
Acqreal	0.4251	0.267	0.1373	0.295	0.386	0.380	0.234	0.5116	0.3252	0.2289
T	24.83	4.793	1.587	1.817	10.816	18.842	11.966	22.86	4.784	5.612
Manpwr	1.599	1.9599	1.9231	1.6919	1.7115	1.7563	2.137	1.5109	2.3311	2.4462
T	43.947	16.216	11.748	5.593	21.767	39.09	49.62	28.526	11.851	22.899
Fleet	-0.012	-0.979	0.387	0.088	-0.437	0.4688	-0.487	-0.967	N/A	-0.082
T	-0.091	-4.627	1.871	0.235	-3.757	4.520	-5.859	-8.699	N/A	-0.101

* SOURCE: regression performed by author

The results of this model more closely resemble the hypothesized relationships than the previous model with overhaul costs included. All HRSUWAY coefficients are positively significant except for CVNs. The only CVN coefficient that is significant is the MANPWR coefficient. This provided a further indication of the abnormality of the CVN data values. It appears that CVNs must use a different O&S costing system. The FLEET coefficients are insignificant for four of the ship types. FLEET was not an appropriate independent variable for SSBNs since none are assigned to the Pacific Fleet. The resulting insignificant FLEET coefficients for CVNs and SSNs are perhaps a result of the previously discussed problems with their respective maintenance and manpower cost data. Deployment differences and mission differences between the Pacific and Atlantic fleets' use of the ship types may be responsible for the differing coefficient signs and significance. This is another area that could benefit from further study.

Using FFs as an example and excluding the effects of overhaul costs on O&S costs, the results of this regression model would be interpreted in the following manner: (1) *ceteris paribus*, a one percent increase in steaming hours will cause O&S costs to increase by 0.1918 percent, (2) *ceteris paribus*, a one percent increase in acquisition costs will cause a 0.234 percent increases in O&S costs, (3) *ceteris paribus*, a one percent increase in the number of personnel on board will increase O&S costs by 2.137 percent, and (4) *ceteris paribus*, if the ship is deployed in Pacific Fleet, O&S

costs will be -0.487 percent less than if the FF were deployed in the Atlantic Fleet.

E. AGGREGATE ANALYSIS BY COLLECTIVE SHIP TYPES

Building upon the results of the individual ship type regressions, the next model treats ship types collectively rather than individually. SSN and CVN data was not used in this collective model nor were overhaul costs. The last section involved regression models by individual ship types in which case the dummy type variables could not be a replacement for other variables. With eight ship types of data collectively in this model, the replacement of the set of ship type dummy variables should be considered. In order to determine the correlation between ACQREAL and MANPWR and to test whether or not the set of ship type dummy variables is an appropriate replacement for ACQREAL and/or MANPWR, seven regressions were performed. Each regression omitted different variables in order to detect the effect of the absence of the omitted variables. Overhaul costs will be discussed separately after this discussion. The results of these regressions are shown in Table 13.

TABLE 13
REGRESSIONS ON EIGHT TYPES COLLECTIVE OBSERVATIONS
WITH DIFFERENT COMBINATIONS OF INDEPENDENT VARIABLES
(O&S COSTS = ELEMENT 1.0 + ELEMENT 2.0 +ELEMENT 4.0)

	1	2	3	4	5	6	7
	Without ship types	Without ship types and manpower	Without ship types and acqreal	With all variables	Without manpower	Without acqreal	Without manpower and acqreal
# of Obs.	1886	1886	1886	1886	1886	1886	1886
F value	986344	1045635	612082	271332	390016	194716	40420
Adj, R^2	0.9995	0.9994	0.9990	0.9994	0.9995	0.9990	0.9948
Intercept	-0.0155	0.0029	0.1983	2.1692	2.5254	0.6450	0.3706
T	-0.458	0.088	6.152	23.170	31.606	6.129	6.366
Hrsuway	0.2952	0.2059	0.3855	0.2532	0.2722	0.3090	2.0366
T	40.758	50.723	41.203	36.629	34.933	34.947	547.851
Acqreal	0.7139	1.1674	-	0.6363	1.1378	-	-
T	65.767	460.943	-	45.734	234.391	-	-
Manpwr	0.8960	-	2.3268	1.1385	-	2.4557	-
T	40.630	-	177.892	38.055	-	197.557	-
Fleet	0.1595	0.3727	-0.1044	-0.2475	-0.1924	-0.1060	0.0403
T	4.183	9.326	-2.976	-3.712	-2.878	-1.520	0.824
FFG	-	-	-	-1.0228	-3.0423	2.0360	-0.1984
T	-	-	-	-7.602	-29.093	18.122	-2.577
CG	-	-	-	-4.5692	-3.8341	-2.4688	0.2530
T	-	-	-	-37.384	-31.594	-19.388	2.908
CGN	-	-	-	-5.8135	-4.5442	-4.2164	0.1273
T	-	-	-	-33.591	-26.327	-23.091	1.015
CV	-	-	-	-6.1190	-3.2848	-5.2166	0.7728
T	-	-	-	-35.130	-19.507	-28.881	6.463
DD	-	-	-	-2.2568	-2.4121	-0.4387	0.2466
T	-	-	-	-20.661	-22.575	-4.124	3.299
DDG	-	-	-	-3.2227	-2.8074	-1.7279	0.1170
T	-	-	-	-31.457	-28.220	-16.665	1.622
SSBN	-	-	-	-4.6802	-6.2336	-0.0629	-1.1042
T	-	-	-	-26.277	-42.783		-9.841

* SOURCE: regression performed by author

1. Regression one

Regression one used the same specification as the second model in the individual aggregate analysis. Since the individual aggregate analysis produced satisfactory results with fewer observations, it is not surprising that this regression with the larger number of collective observations provided even better results. The F value and adjusted R^2 are 986,334 and 0.9995 respectively. Except for the intercept, all other coefficients are highly significant. The FLEET coefficient indicates that a ship assigned to the Pacific Fleet spends 0.1595 percent higher O&S costs (without considering overhaul costs) than if it is assigned to the Atlantic Fleet.

2. Regressions two and three

Because of the suspicion of correlation between ACQREAL and MANPWR, these variables were individually removed in regressions 2 and 3. In regression 2 with MANPWR omitted, the ACQREAL and FLEET coefficients were considerably affected. The ACQREAL coefficient changed from 0.7139 to 1.1674 and the FLEET coefficient changed from 0.1595 to 0.3727. The other parameters only changed slightly and the intercept remained insignificant. Notice also that the ACQREAL T-statistic changed from 65.767 to 460.943 but the HRSUWAY T-statistic changed only from 40.758 to 50.723. This indicates that MANPWR is highly correlated with ACQREAL but not with HRSUWAY. ACQREAL is a dominating factor in regression 2. Nevertheless, the ACQREAL coefficient changed considerably, so the independent variable MANPWR indeed explains something that ACQREAL could not.

Conversely, when ACQREAL is omitted from equation one, all coefficients changed drastically. This time the T statistic for MANPWR changed from 40.630 to 177.892 and the coefficient changed from 0.8960 to 2.3268. The intercept became positively significant and FLEET became negatively significant. This larger influence indicates that ACQREAL is a closer proxy for O&S costs (excluding overhaul cost).

The outcomes of regressions 2 and 3 strongly suggest that both ACQREAL and MANPWR explain some part of the O&S costs (excluding overhaul costs) that the other can not. Therefore, they are both relevant independent variables in the equation. Their relationships with O&S costs (excluding overhaul costs) and between themselves are depicted in Figure 5.

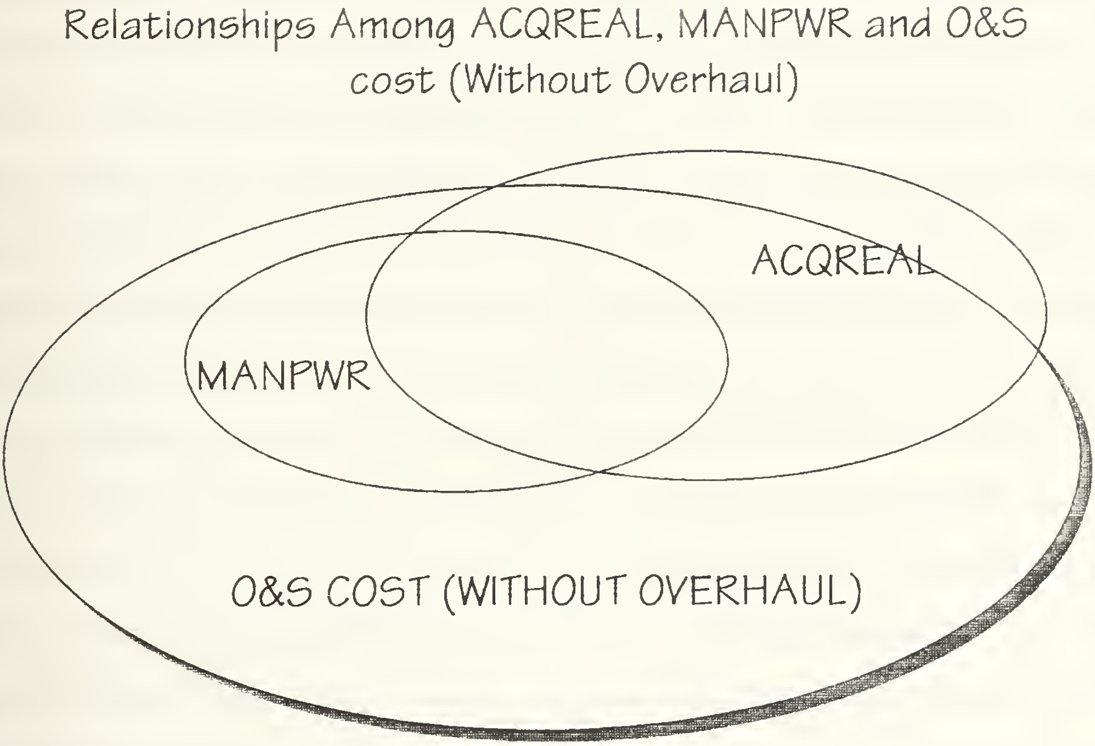
Relationships Among ACQREAL, MANPWR and O&S cost (Without Overhaul)
ACQREAL
MANPWR
O&S COST (WITHOUT OVERHAUL)

Figure 5: Relationships among ACQREAL, MANPWR and O&S cost (Without Overhaul).

3. Regressions four, five, six and seven

These regressions are intended to determine whether the set of ship type dummy variables is a good replacement for

ACQREAL and MANPWR variables. Regression four is developed by adding the set of ship type dummy variables to the model used in regression one. The results of regression four show that by adding the ship type dummy variables, the FLEET coefficient changes from positively significant to negatively significant. The intercept also changes in order to compensate for the coefficients of the dummy variables. The largest change in other coefficients occurred in the MANPWR variable, but the change was not as dramatic as in regressions 2 and 3 and the T-statistic was only slightly altered. Although the adjusted R^2 remained very high (it actually is the highest for all of the regressions), the F value dropped considerably --from 986344 to only 271332. Taking a closer look at the ship type coefficients, the bigger the average tonnage of the ship the bigger the absolute value of the negative number for the coefficient. Does this mean that larger ships have lower O&S costs (exclusive of overhaul costs)? In order to obtain more information relating to this apparent paradox, the following regressions were examined.

Regressions five and six duplicate regression two and three except the ship type dummy variables are added to the models. Omitting ACQREAL and MANPWR individually results in changes identical to regressions two and three. This adds further support for the aforementioned interrelationships between ACQREAL, MANPWR and O&S costs (excluding overhaul cost) and also gives an indication that the set of ship type dummy variables does not affect other independent variables.

Regression seven considers the case where both ACQREAL and MANPWR are omitted and replaced with the set of ship type dummy variables. This set of dummy variables, therefore, represents the size, equipment installed, manpower and operational tempo characteristics. The results are surprising. The model does not support the assertion that the set of ship type dummy variables is an adequate substitute for the ACQREAL and MANPWR variables. Also, the independent variable HRSUWAY captured the remaining variation since the coefficient jumped from 0.2952 to 2.0366. Three of the dummy variables had insignificant coefficients and those with significant coefficients had very small values. These results strongly suggest that the ship type dummy variables are not directly relevant to O&S costs (excluding overhaul costs) and are not replacements for the ACQREAL and MANPWR variables. It can also be said that the dummy variables are not relevant because they did not capture any meaningful variation in regression seven. Among the seven regressions, the initial model--the first model with no ship type dummy variables and with both ACQREAL and MANPWR independent variables included--is the best choice for explaining O&S cost relationships.

F. OVERHAUL COST PROBLEM

Up until this point the effects of overhaul costs on O&S costs have been ignored. What about the overhaul costs?

Since the accounting approach defines scheduled overhaul costs as a function of engine shut down hours and year, if a regression is redone on only the eight ship types using this accounting-oriented specification, the results will be similar to the overall overhaul regression discussed in part one. That regression does not provide useful information for future forecasting or simulation. What is desired is to construct a structural equation on only overhaul costs since this cost component could not be integrated into the aggregate O&S costs analysis.

In addition to the "data year" factor (this is a factor because of the overhaul policy change), there are two other possible factors that could influence overhaul costs. The first one is, once again, the acquisition cost in real terms. An expensive ship could mean a bigger ship, more equipment on board and hence more work when overhauled. It also could mean new technology which can, by itself, reduce the cost of overhaul, but this kind of influence will not easily overcome the costs associated with size and equipment. Therefore, it is expected that the coefficient of ACQREAL will be positively significant.

A second factor to consider is the FLEET to which the ship is assigned. Since it has been shown that ships will have different O&S costs (excluding overhaul costs) depending upon which fleet they are assigned to, there could be overhaul cost differences as well. A logical assertion (based upon the previously presented analysis) is that Pacific Fleet overhaul costs are higher because of the larger geographical areas that must be covered. Extending the dummy variable and dummy slope approach to structural overhaul analysis, a log-linear regression model will be specified as follows:

$$\ln(\mathit{Overhaul\ Cost}) = \phi_0 + \phi_1 \ln(\mathit{ACQREAL}) + \phi_2 \mathit{FLEET} + \phi_3 \mathit{OLD} + \phi_4 \mathit{OLD}_{\mathit{YEAR}} + \phi_5 \mathit{YOUNG} + \phi_6 \mathit{YOUNG}_{\mathit{YEAR}} \tag{8}$$

The regression result obtained is shown in Table 14 and compared with the accounting-oriented regression for ease in interpretation.

TABLE 14
OVERHAUL COSTS STRUCTURAL REGRESSION AND ACCOUNTING ORIENTED REGRESSION RESULT COMPARISON

	STRUCTURAL	ACCOUNTING ORIENTED
F value	185	7022
adjusted R^2	0.3373	0.9448
Intercept	0.1004	0.1071
T	0.236	0.417
ACQREAL	0.7678	-
T	28.947	-
HRSNOWAY	-	1.7251
T	-	170.793
FLEET	0.7115	-
T	2.870	-
OLD	37.9334	3.2428
T	8.444	6.193
OLDYEAR	-0.4330	-0.382
T	-8.249	-6.252
YOUNG	-51.2633	-12.2666
T	-4.282	-7.049
YOUNGYEAR	0.5652	0.1390
T	4.109	6.934

* SOURCE: regression performed by author

The accounting-oriented regression has the specification employed in the data authentication part of this research. The result of the regression is quite good and, engine shut down hours dominates the model. As we discussed earlier, this regression serves the purpose of data authentication.

The structural regression, which describes the effect of technology and policy on overhaul costs, has a lower adjusted R^2 and lower F value but significant coefficients (except the intercept). These results appear to be normal for a regression model explaining an intermittently occurring event, provided that the period between the event is unknown. If we had enough information about the period between overhauls, a lag term could be introduced to capture this effect, and the structural regression results might be expected to improve. This could be another topic for future research.

G. ADJUSTED AGGREGATE ANALYSIS MODEL

The final models for both O&S costs with and without overhaul costs can be developed. The original model should be adjusted based on our findings, and the new aggregate analysis model should appear as shown in Figure 6.

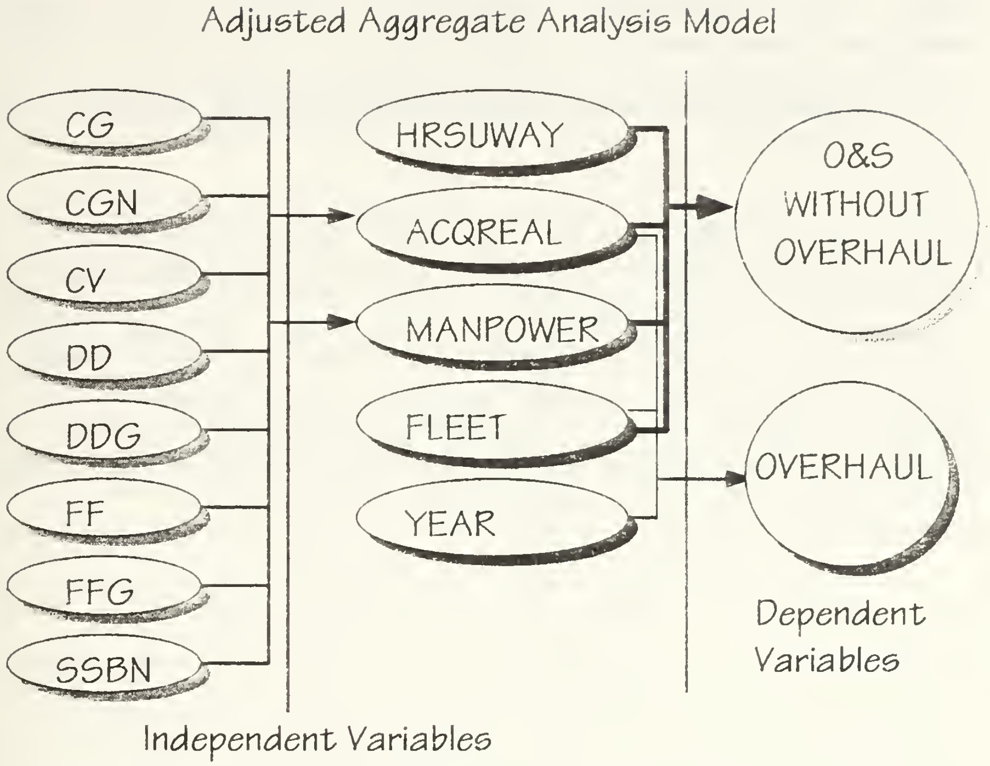

Figure 6: Adjusted aggregate analysis model.

Figure 6 shows that O&S costs (excluding overhaul cost) are a function of steaming hours underway (HRSUWAY), acquisition cost in real term (ACQREAL), the number of personnel assigned on board (MANPWR) and the fleet to which the ship belongs (FLEET). Overhaul cost is a function of ACQREAL, FLEET and data year of the observation (YEAR).

H. SHORT CONCLUSION FOR AGGREGATE ANALYSIS

The following observations are worth mentioning:

- **Changing of the Navy's overhaul policy had little or no influence on subcategories other than overhaul cost.** The final model for O&S costs does not contain a year variable. It will not be difficult to forecast on all subcategories except overhaul because overhaul is sensitive to the year of observation and no conclusion is made regarding whether or not the policy change effects have reached steady state.

- **When doing aggregate analysis, overhaul cost must be analyzed separately.** When analyzing O&S costs including overhaul costs, the steaming hours underway coefficient will become negative because of the complementary effect with engine shut down hours and overhaul costs being larger than material costs.

- **Manpower always has the largest coefficient.** A larger coefficient means a larger percentage change in O&S costs (excluding overhaul cost) when there is a one percent increase in the independent variable. Hence, MANPWR is the most efficient factor to use in cost reduction. Given a fixed O&S budget, detailed simulation analysis might be employed to determine the extend to which a more efficient use of manpower might enable the U.S. Navy to maintain a larger number of ships than are currently planned.

IV. CONCLUSIONS AND RECOMMENDATIONS

Because of the overhaul policy change, overhaul costs were transitioning to a new steady state. We have no evidence to conclude that the transition has ended, hence forecasting for the overhaul costs subcategory is limited without batter information. Given the assumption that the transition period to steady state takes five years, additional data might indicate that this transition has been completed.

Manpower cost is a very big portion of total O&S costs and the analysis results show that managing manpower issues has the largest impact on O&S cost saving decisions and efficiently allocating O&S costs. This area of research is most strongly recommended for future study.

The Republic of China's Navy derived its O&S costing system from the U.S. Navy. Although institutional difference might be an issue, this study could be useful reference for the R.O.C. Navy given its clear results and well defined models and methodologies.

Generally speaking, the observations in this dataset are valid for any further research except for certain types of ships (e.g. CVN and SSN). Follow-on researchers should have sufficient institutional knowledge and be familiar with the operating and support cost system to fully explore the relationships in this database.

Finally, the research results are valuable in establishing the reliability of the VAMOSC-SHIPS database and in understanding O&S cost relationships. As the research progressed, additional areas of interest were discovered, but they are beyond the scope of this study. By investigating these areas, a more thorough understanding of O&S costs could be obtained.

APPENDIX A. ALL ELEMENTS IN THE VAMOSC DATA

1.0	DIRECT UNIT COSTS
1.1	PERSONNEL
1.1.1	MANPOWER
1.1.1.1	REPORTED MAINT LABOR MANHRS
1.1.1.2	OFFICER MANPOWER
1.1.1.3	ENLISTED MANPOWER
1.1.2	TAD
1.2	MATERIAL
1.2.1	SHIP POL
1.2.1.1	FUEL (FOSSIL)
1.2.1.1.1	UNDERWAY
1.2.1.1.2	NOT UNDERWAY
1.2.1.2	OTHER POL
1.2.1.3	BARRELS OF FUEL CONSUMED
1.2.1.3.1	UNDERWAY
1.2.1.3.2	NOT UNDERWAY
1.2.2	REPAIR PARTS
1.2.3	SUPPLIES
1.2.3.1	EQUIPMENT/EQUIPAGE
1.2.3.2	CONSUMABLES
1.2.3.3	SHIPS FORCE MATERIAL
1.2.4	TRAINING EXPENDABLE STORES

1.2.4.1	AMMUNITION
1.2.4.2	OTHER EXPENDABLES
1.2.5	REPAIRABLES
1.2.5.1	ORGANIZATIONAL EXCHANGES
1.2.5.2	ORGANIZATIONAL ISSUES
1.3	PURCHASED SERVICES
1.3.1	PRINTING AND REPRODUCTION
1.3.2	ADP RENTAL & CONTRACT SERVICES
1.3.3	RENT AND UTILITIES
1.3.4	COMMUNICATIONS
1.3.5	OTHER
2.0	DIRECT INTERMED MAINTENANCE
2.1	AFLOAT MAINTENANCE LABOR
2.1.1	AFLOAT MAINT LABOR MANHRS
2.2	ASHORE MAINTENANCE LABOR
2.2.1	ASHORE MAINT LABOR MANHRS
2.3	MATERIAL
2.3.1	AFLOAT REPAIR PARTS
2.3.2	ASHORE REPAIR PARTS
2.4	COMMERCIAL INDUSTRIAL SERVICES
3.0	DIRECT DEPOT MAINTENANCE
3.1	SCHEDULED SHIP OVERHAUL
3.1.1	REGULAR OVERHAUL (SLEP)
3.1.1.1	PUBLIC SHIPYARD (SLEP)

3.1.1.1.1 OVERHEAD (SLEP)

3.1.1.1.2 LABOR (SLEP)

3.1.1.1.2.1 MANDAYS (SLEP)

3.1.1.1.3 MATERIAL (SLEP)

3.1.1.2 PRIVATE SHIPYARD

3.1.1.3 SHIP REPAIR FACILITY

3.1.1.3.1 OVERHEAD

3.1.1.3.2 LABOR

3.1.1.3.3 MATERIAL

3.1.2 SELECTED RESTRICTED AVAIL

3.1.2.1 PUBLIC SHIPYARD

3.1.2.1.1 OVERHEAD

3.1.2.1.2 LABOR

3.1.2.1.2.1 MANDAYS

3.1.2.1.3 MATERIAL

3.1.2.2 PRIVATE SHIPYARD

3.1.2.3 SHIP REPAIR FACILITY

3.1.2.3.1 OVERHEAD

3.1.2.3.2 LABOR

3.1.2.3.3 MATERIAL

3.2 NON-SCHEDULED SHIP REPAIR

3.2.1 RESTRICTED AVAILABILITY

3.2.1.1 PUBLIC SHIPYARD

3.2.1.1.1 OVERHEAD

3.2.1.1.2 LABOR

3.2.1.1.2.1 MANDAYS

      - 3.2.1.1.3 MATERIAL
    - 3.2.1.2 PRIVATE SHIPYARD
    - 3.2.1.3 SHIP REPAIR FACILITY
      - 3.2.1.3.1 OVERHEAD
      - 3.2.1.3.2 LABOR
      - 3.2.1.3.3 MATERIAL
  - 3.2.2 TECHNICAL AVAILABILITY
    - 3.2.2.1 PUBLIC SHIPYARD
      - 3.2.2.1.1 OVERHEAD
      - 3.2.2.1.2 LABOR
        - 3.2.2.1.2.1 MANDAYS
      - 3.2.2.1.3 MATERIAL
    - 3.2.2.2 PRIVATE SHIPYARD
    - 3.2.2.3 SHIP REPAIR FACILITY
      - 3.2.2.3.1 OVERHEAD
      - 3.2.2.3.2 LABOR
      - 3.2.2.3.3 MATERIAL
- 3.3 FLEET MODERNIZATION (SLEP)
  - 3.3.1 PUBLIC SHIPYARD (SLEP)
    - 3.3.1.1 OVERHEAD
    - 3.3.1.2 LABOR
      - 3.3.1.2.1 MANDAYS
    - 3.3.1.3 MATERIAL
  - 3.3.2 PRIVATE SHIPYARD
  - 3.3.3 SHIP REPAIR FACILITY
    - 3.3.3.1 OVERHEAD

        - 3.3.3.2 LABOR
        - 3.3.3.3 MATERIAL
    - 3.3.4 CENTRALLY PROVIDED MATERIAL
    - 3.3.5 OTHER
    - 3.3.6 OUTFITTING AND SPARES
  - 3.4 OTHER DEPOT
    - 3.4.1 NAVAL AVIATION DEPOT
      - 3.4.1.1 OVERHEAD
      - 3.4.1.2 LABOR
      - 3.4.1.3 MATERIAL
    - 3.4.2 FIELD CHANGE INSTALLATION
    - 3.4.3 REWORK
      - 3.4.3.1 ORDNANCE REWORK
      - 3.4.3.2 HM&E REWORK
      - 3.4.3.3 ELECTRONIC REWORK
    - 3.4.4 DESIGN SERVICES ALLOCATION

- 4.0 INDIRECT OPERATING & SUPPORT
  - 4.1 TRAINING
  - 4.2 PUBLICATIONS
  - 4.3 ENGINEERING & TECH SERVICES
  - 4.4 AMMUNITION HANDLING

APPENDIX B. LIST OF PRELIMINARY RESEARCH REGRESSIONS

The following is a partial chronological list of regressions performed.

1. MN5003: Regression on individual ship of class 0963 using average values.
2. MN5004: Regression on year of class 0963 using average values.
3. MN6003: Same regression as MN5003 but with different specification on dependent variable.
4. MN6004: Same regression as MN5004 but with different specification on dependent variable.
5. MN6005: Dealt specifically with overhaul cost using all observations.
6. MN6006: Structural regression on total O&S cost using only class 0963 ships.
7. MN6001: A rewritten program. Same as MN6006 but using different independent variables.
8. TH00001: Divided the O&S cost into several subcategories and do accounting oriented regressions on each subcategory. Only class 0963.
9. TH0000: Same program as TH00001 but using the whole observations.
10. TH0004: Use different independent variables and redo program TH0000.
11. TH0003: Do same regression as TH0004 down to individual ship level.
12. TH0006: Do same regression as TH0004 but regress on cross sectional annual data.
13. TH0007: Regression of steaming hours underway to year, try to find the decreasing tendency of steaming hours.

14. TH0008: Using same specification as TH0003 to regress only class 0963 and found there are some outliers.

15. TH00081: Redefine dependent and independent variables and do accounting oriented regression again on only class 0963 ships.

16. MN6002: A revised program with different linear combination of independent variables.

17. MN60011 and MN60012: Same regression as MN6002 but regress on individual ship and annual data respectively.

18. TH0010: Using PROC AUTOREG procedure in the SAS language to deal with the serial correlation problem.

19. TH0011: Using pooled data method and wrote a SAS program to deal with serial correlation and heteroskedasticity simultaneously.

20. Regroup the data according to type of ship and developed a model on authenticating the data.

21. Found the Navy had changed its overhaul policy and developed an assumption on old and new ships.

22. Found that there are more missing values in the database.

APPENDIX C. SAS PROGRAM OF THE MATHEMATICAL MODEL

```
* RESTRICT THE OBSERVATION TO ONLY THE TEN TYPES WE WANTED.
  IF TYPE='CG' OR TYPE='CGN' OR TYPE='CV' OR TYPE='CVN' OR TYPE='DD' OR
  TYPE='DDG' OR TYPE='FF' OR TYPE='FFG' OR TYPE='SSBN' OR TYPE='SSN';

* RESTRICT THE DEPENDENT VARIABLES TO THE SUB-ELEMENTS WE
WANTED.
  MP=SE111;
  LMP=LOG(MP);
  MAT=SE12+SE13;
  LMAT=LOG(MAT);
  MH=SE21+SE22;
  IF MH=0 THEN MH=1;
  LH=LOG(MH);
  OV=SE31;
  IF OV=0 THEN OV=1;
  LOV=LOG(OV);
  NEWOS=SE10+SE20+SE31+SE40;
  LNEWOS=LOG(NEWOS);

* GET INDIVIDUAL SHIP'S EARLIEST AND LATEST OBSERVATION
YEAR.
  PROC SORT; BY GROUP SHIPNAME;
  PROC MEANS NOPRINT; BY GROUP SHIPNAME;
       VAR YR;
       OUTPUT OUT=MAN MIN=LOW MAX=HIGH;

* MERGE THE EARLIEST AND LATEST OBSERVATION YEAR TO THE
ORIGINAL DATABASE.
  DATA TWO;
  MERGE ONE MAN;
  BY GROUP SHIPNAME;

* IF THE OBSERVATIONS FOR CERTAIN SHIPS ARE LESS THAN 2,
DELETE THEM BECAUSE OF THE MATHEMATICAL CALCULATION NEED
MORE OBSERVATIONS THAN THE NUMBER OF DEPENDENT VARIABLES.
  DATA THREE (KEEP=MP OFFNAVY ENLNAVY SHIPNAME YR TYPE LOW HIGH);
  SET TWO;
  IF HIGH-LOW LE 1 THEN DELETE;

* REGRESS BY TYPE TO GET THE FIRST TIME RESIDUALS
  PROC SORT; BY TYPE SHIPNAME YR;
  PROC REG; BY TYPE;
    MODEL MP=OFFNAVY ENLNAVY;
    OUTPUT OUT=MANPOWER R=MPRESID;
  PROC SORT DATA=MANPOWER; BY TYPE SHIPNAME YR;

* CALCULATE THE NUMERATOR AND DENOMINATOR OF THE
MATHEMATICAL PART.
  DATA FOUR (KEEP=MPRESID MP OFFNAVY ENLNAVY SHIPNAME YR LOW HIGH TYPE
             UP DOWN1 DOWN2 LMPRESID);
  SET MANPOWER;
  LMPRESID=LAG(MPRESID);
  IF YR=LOW THEN UP=0;
  IF YR GT LOW THEN UP=MPRESID*LMPRESID;
  IF YR=LOW THEN DOWN1=0;
  IF YR GT LOW THEN DOWN1=MPRESID**2;
  IF YR=LOW THEN DOWN2=0;
  IF YR GT LOW THEN DOWN2=LMPRESID**2;

* CALCULATE THE FINAL RESULT OF THE ρ.
  PROC MEANS NOPRINT;VAR UP DOWN1 DOWN2; BY TYPE SHIPNAME;
  OUTPUT OUT=ANYNAME SUM=SUMUP SUMDOWN1 SUMDOWN2;

* MERGE THEM TO THE DATABASE.
  DATA FIVE;
  MERGE FOUR ANYNAME;
  BY GROUP SHIPNAME;

* CALCULATE THE ESTIMATED VALUE OF THE DEPENDENT AND
INDEPENDENT VARIABLES USING THE ρ CALCULATED BY PREVIOUS
PROCEDURES.
  DATA SIX (KEEP=MPRESID MP OFFNAVY ENLNAVY SHIPNAME YR LOW HIGH TYPE
            UP DOWN1 DOWN2 RHO SUMUP SUMDOWN1 SUMDOWN2 NEWMP NEWOFF
            NEWENL LMP LOFFNAVY LENLNAVY);
  SET FIVE;
  RHO=SUMUP / (SQRT(SUMDOWN1)*SQRT(SUMDOWN2));
  LMP=LAG(MP);
  LOFFNAVY=LAG(OFFNAVY);
  LENLNAVY=LAG(ENLNAVY);
  IF YR=LOW THEN NEWMP=SQRT(1-RHO**2)*MP;
  IF YR GT LOW THEN NEWMP=MP-RHO*LMP;
  IF YR=LOW THEN NEWOFF=SQRT(1-RHO**2)*OFFNAVY;
  IF YR GT LOW THEN NEWOFF=OFFNAVY-RHO*LOFFNAVY;
  IF YR=LOW THEN NEWENL=SQRT(1-RHO**2)*ENLNAVY;
  IF YR GT LOW THEN NEWENL=ENLNAVY-RHO*LENLNAVY;

* DO THE SECOND TIME REGRESSION TO GET THE SECOND TIME
RESIDUAL.
  DATA SEVEN (KEEP=SHIPNAME YR LOW HIGH TYPE NEWMP NEWOFF NEWENL);
  SET SIX;
  PROC SORT; BY TYPE SHIPNAME YR;
  PROC REG; BY TYPE;
  MODEL NEWMP=NEWOFF NEWENL;
  OUTPUT OUT=MANP R=MP2RESID;

* FIRST STEP CALCULATION OF THE μ ACCORDING TO THE
MATHEMATICAL PROCEDURE.
  DATA EIGHT (KEEP=SHIPNAME YR LOW HIGH TYPE NEWMP NEWOFF NEWENL
              MP2RESID);
  SET MANP;
  MP2RESID=MP2RESID**2;

  PROC MEANS DATA=EIGHT NOPRINT; VAR MP2RESID; BY TYPE SHIPNAME;
  OUTPUT OUT=ANY SUM=SUMMP2RE;

* MERGE THEM TO THE DATABASE.
  DATA NINE;
  MERGE ANY EIGHT;
  BY GROUP SHIPNAME;
```

```
* SECOND STEP CALCULATION OF THE μ ACCORDING TO THE
MATHEMATICAL PROCEDURE.
  DATA TEN (KEEP=SHIPNAME YR LOW HIGH TYPE NEWMP NEWOFF NEWENL HIGH
            SUMMP2RE FINMP FINOFF FINENL SUI);
  SET NINE;
  SUI=SQRT(1/((HIGH-LOW+1)-2)*SUMMP2RE);
  FINMP=NEWMP/SUI;
  FINOFF=NEWOFF/SUI;
  FINENL=NEWENL/SUI;

* THIRD TIME REGRESSION TO GET THE FINAL RESULT OF THE
MODEL.
  DATA ELEVEN (KEEP=SHIPNAME YR TYPE FINMP FINOFF FINENL);
  SET TEN;
  PROC REG; BY TYPE;
  MODEL FINMP=FINOFF FINENL;
```

APPENDIX D. OVERHAUL REGRESSIONS BY TYPE

REGRESSIONS ON OVERHAUL BY TYPES WITH
DIFFERENT COMMISSIONED YEAR CRITERIA
(AFTER 80 - YOUNG, BEFORE 76 - OLD)

	CG (193)	CGN (89)	CV (87)	CVN (38)	DD (307)	DDG (353)	FF (496)	FFG (204)	SSBN (322)	SSN (836)
F value	55	56	496	10	27	107	206	28	34	175
R^2	0.5307	0.656	0.9201	0.5617	0.3012	0.5482	0.4542	0.4041	0.2974	0.5116
Noway	1.6016	1.9230	1.927	1.045	1.4815	1.552	1.6227	0.859	1.1144	1.6282
T	13.377	9.111	5.130	4.931	10.738	-1.415	20.024	8.166	7.879	28.88
Old	17.383	4.297	N/A	-5.178	7.2132	12.821	N/A	2.1618	14.948	0.8791
T	1.929	1.607	N/A	-0.504	2.408	2.969	N/A	0.638	2.859	1.060
Young	N/A	N/A	N/A	0.097	12.037	N/A	N/A	-9.101	N/A	-2.332
T	N/A	N/A	N/A	0.005	1.028	N/A	N/A	-4.976	N/A	-1.067
Oldyear	-0.066	-0.049	-0.141	0.063	-0.084	-0.084	-0.048	-0.019	-0.0899	-0.010
T	-3.679	-1.586	-5.177	0.524	-2.409	-6.035	-4.415	-0.478	-6.402	-1.081
Youngyr	0.1326	N/A	N/A	-0.019	-0.145	0.065	N/A	0.1065	0.0775	0.025
T	1.302	N/A	N/A	-0.079	-1.079	1.343	N/A	5.073	1.322	1.008

* SOURCE: regression performed by author

The dependent variable here is the same as used regression in section III.F. The independent variables have been categorized into three different group of ships. The OLD and YOUNG are dummy variables denoting whether the ship was commissioned before year 1976 or after year 1980 (not including years 1976 and 1980). The ships between years 1976 and 1980 will be the default group (including years 1976 and 1980).

We can easily see from the above table that most of the cells in the table are shaded because either data are not available (N/A) or coefficients are insignificant. The "N/A" in the table means there is no observation in the group and hence no coefficient could be obtained.

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